Spectral analysis of the acoustic near field of a solid propellant rocket

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Measurements of Unsteady Pressure Fluctuations near the Plume of a Solid Rocket Motor

William C. Horne, Nathan J. Burnside, Jayanta Panda
NASA Ames Research Center, Moffett Field, CA

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NASA Wallops Flight Facility, Wallops Island, VA

International Journal of Aeroacoustics, 2016
Vol. 15, pp. 554-569.

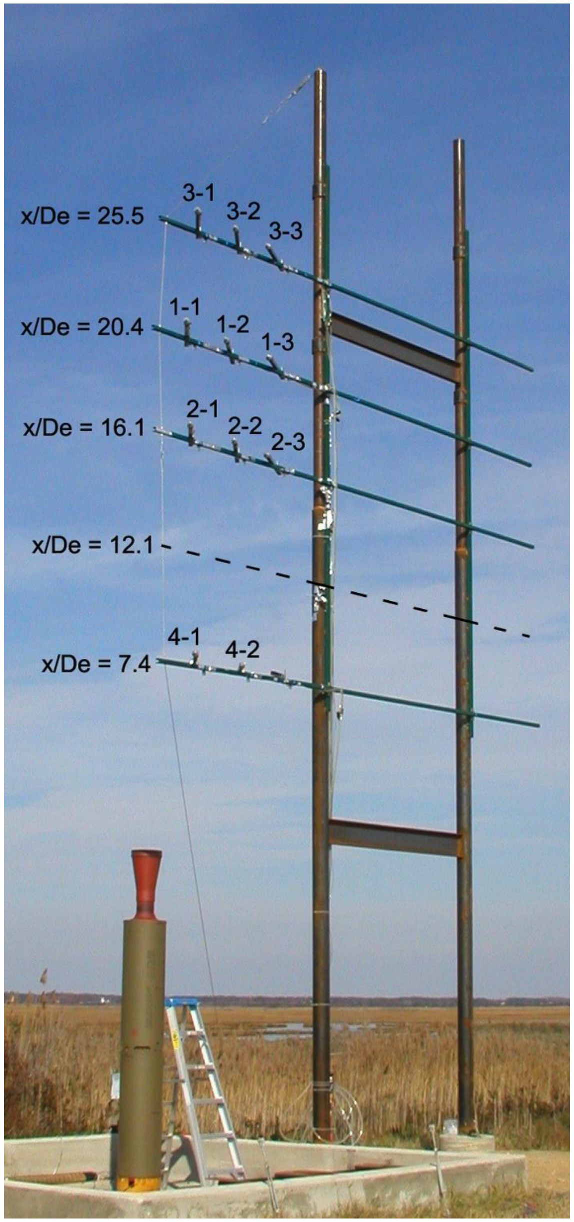
Outline

1. Brief review of NASA Ames Research Center rocket noise experiment.
2. The challenges.
3. Review of the dominant noise components of hot supersonic laboratory jets.
4. Applicability of similarity spectra to near field high speed jet noise.
5. Applicability of similarity spectra to rocket noise.

Brief review of NASA Ames Research Center rocket noise experiment.

“ Measurements of Unsteady Pressure Fluctuations near the Plume of a Solid Rocket Motor” by W. C. Horne, N. J. Burnside, J. Panda and C. Brodell published in the International Journal of Aeroacoustics, 2016, Vol. 15, pp. 554-569.

- Spectral data in the near field of the rocket plume are provided.
- Experiment consists of two tests: high burn and low burn



15 microphones

low burn

high burn

The Challenges are :

We have spectral data from 15 microphones.

Can we use this information to determine:

1. the dominant noise components in the near field of a solid propellant rocket.
2. the spatial distribution of the dominant noise components in the near field and their sources.

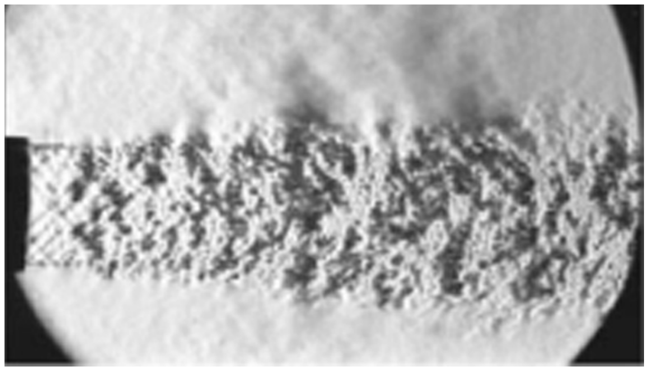
Dominant noise components of hot supersonic laboratory jets in the far field

Turbulent mixing noise

- Fine scale turbulence noise
- Large turbulence structures noise

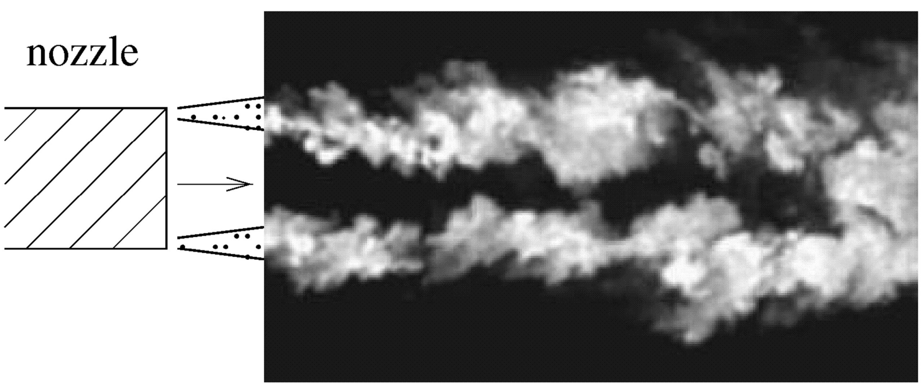
Broadband shock cell noise

Jet Mixing Noise



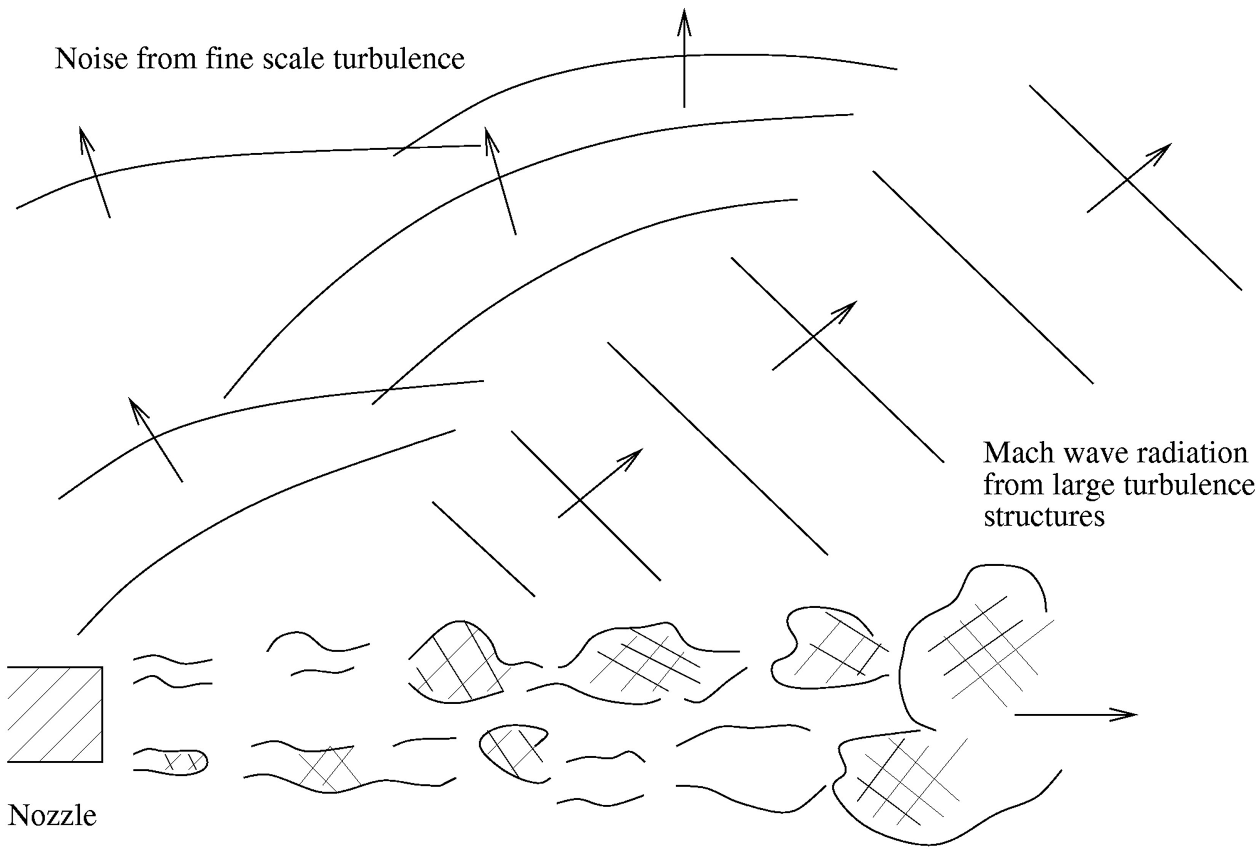
Small blobs of turbulence or fine scale turbulence

Spark schlieren photograph of a Mach 1.4 jet.

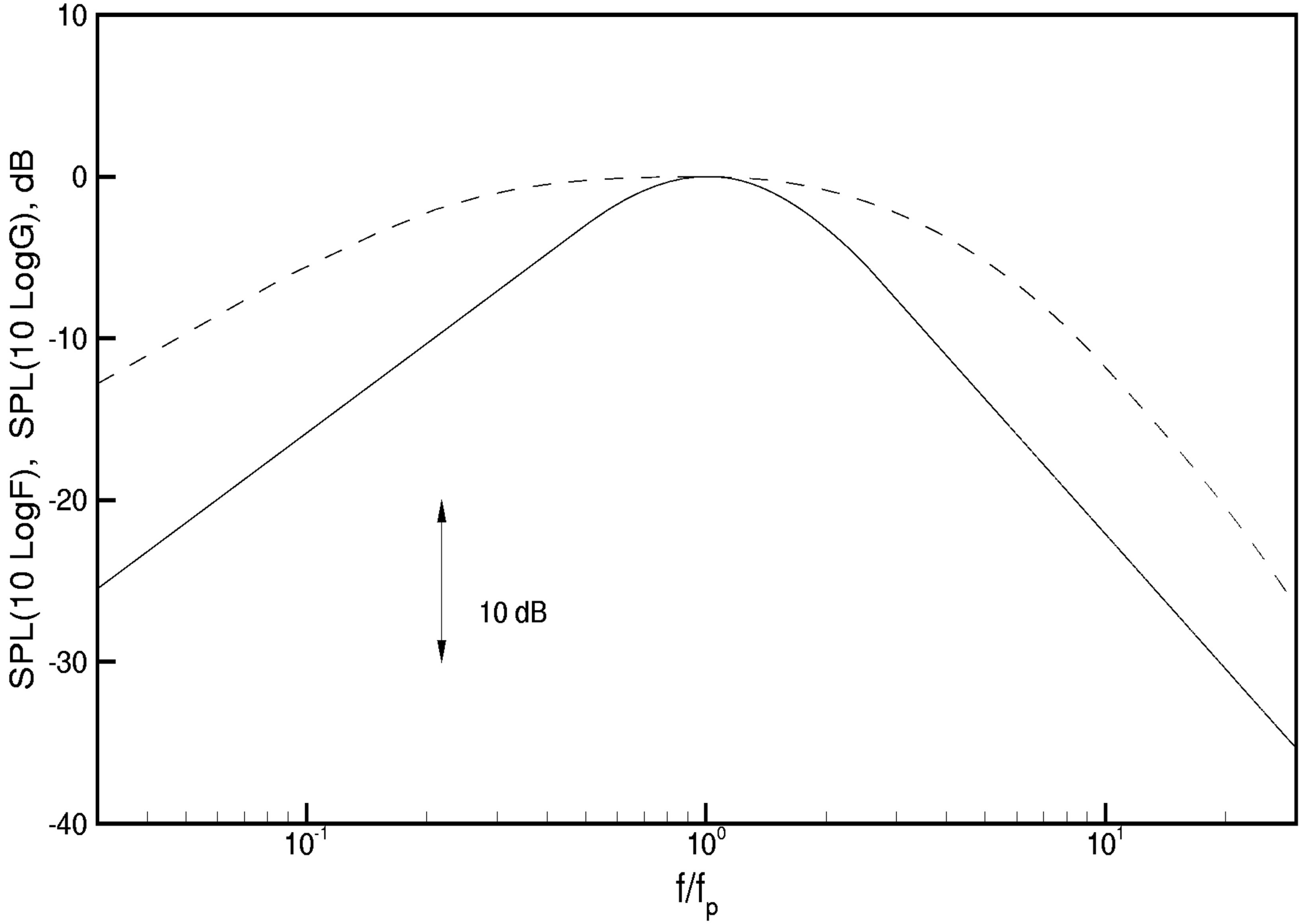


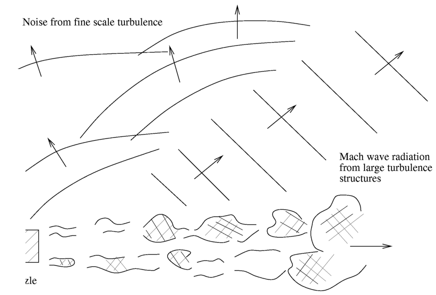
Large turbulence structures

Pulsed laser picture of the large turbulence structures in the mixing layer of a Mach 1.3 jet

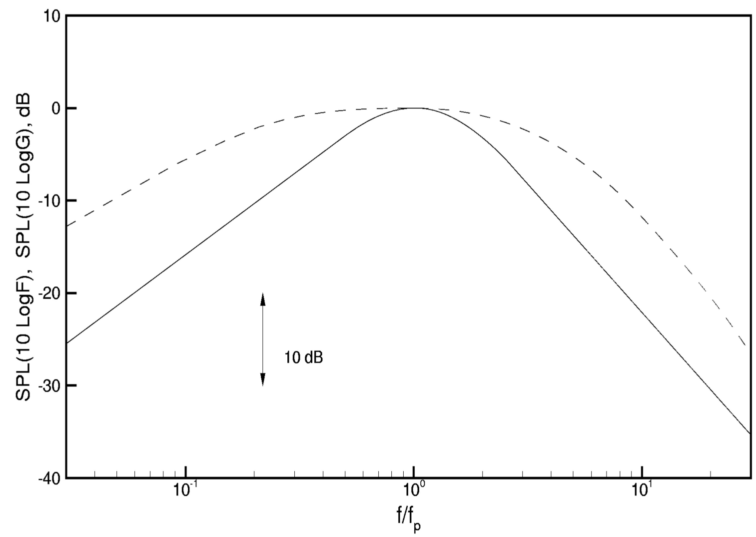


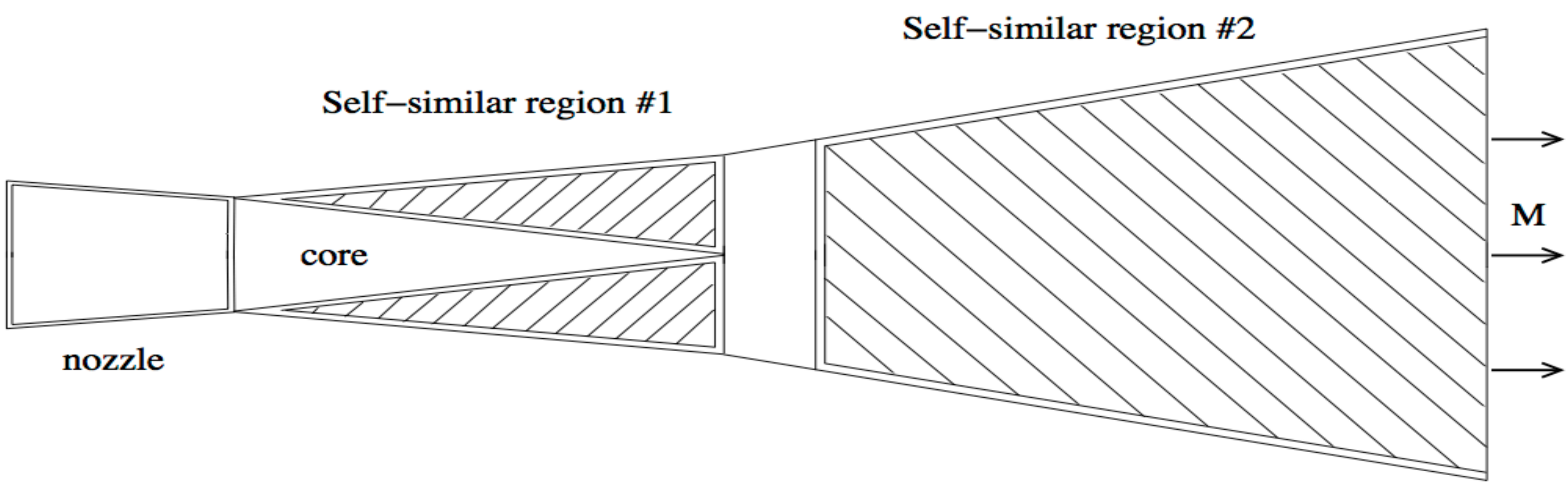
The two noise-source model of high-speed jets



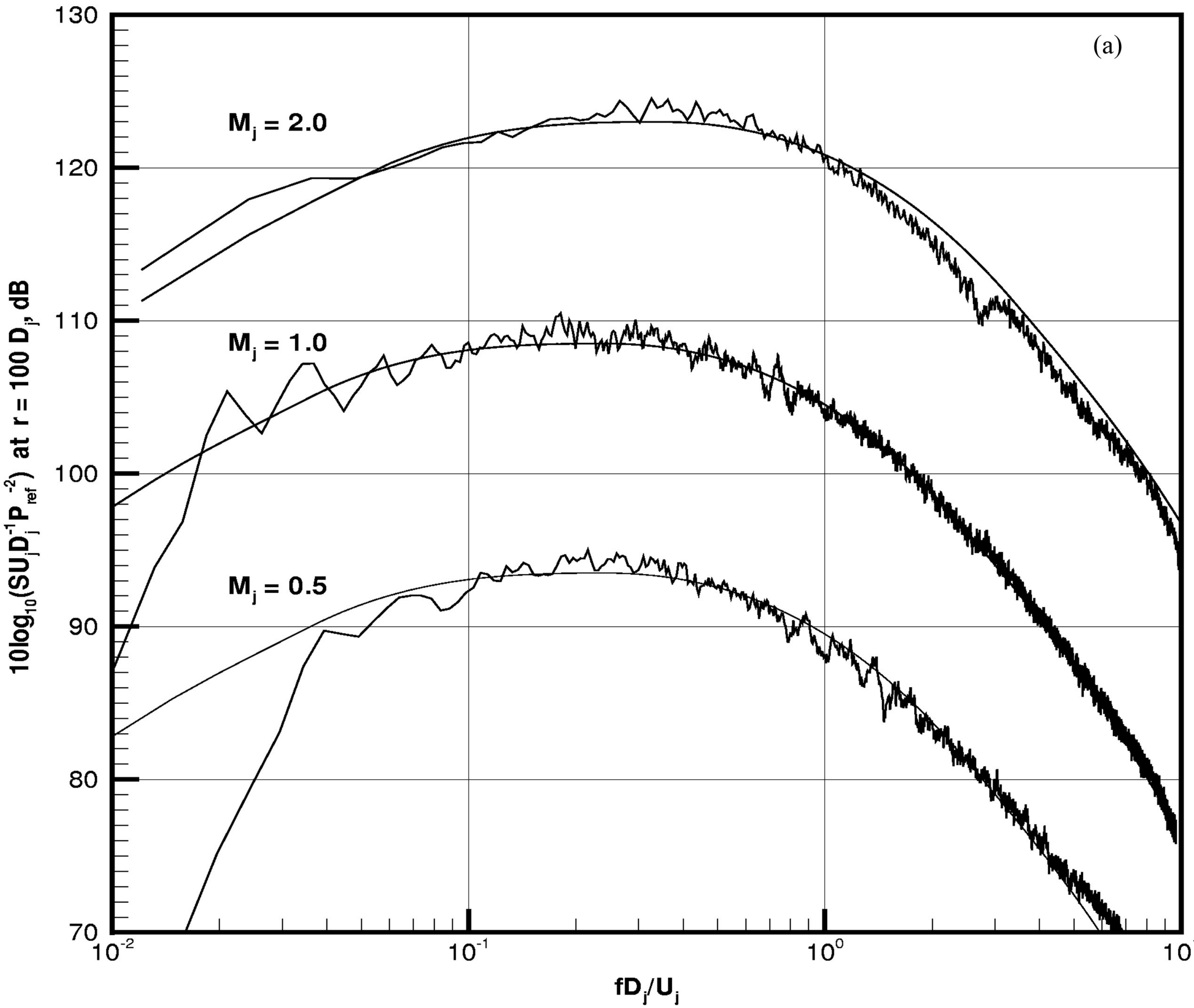


The two similarity spectra

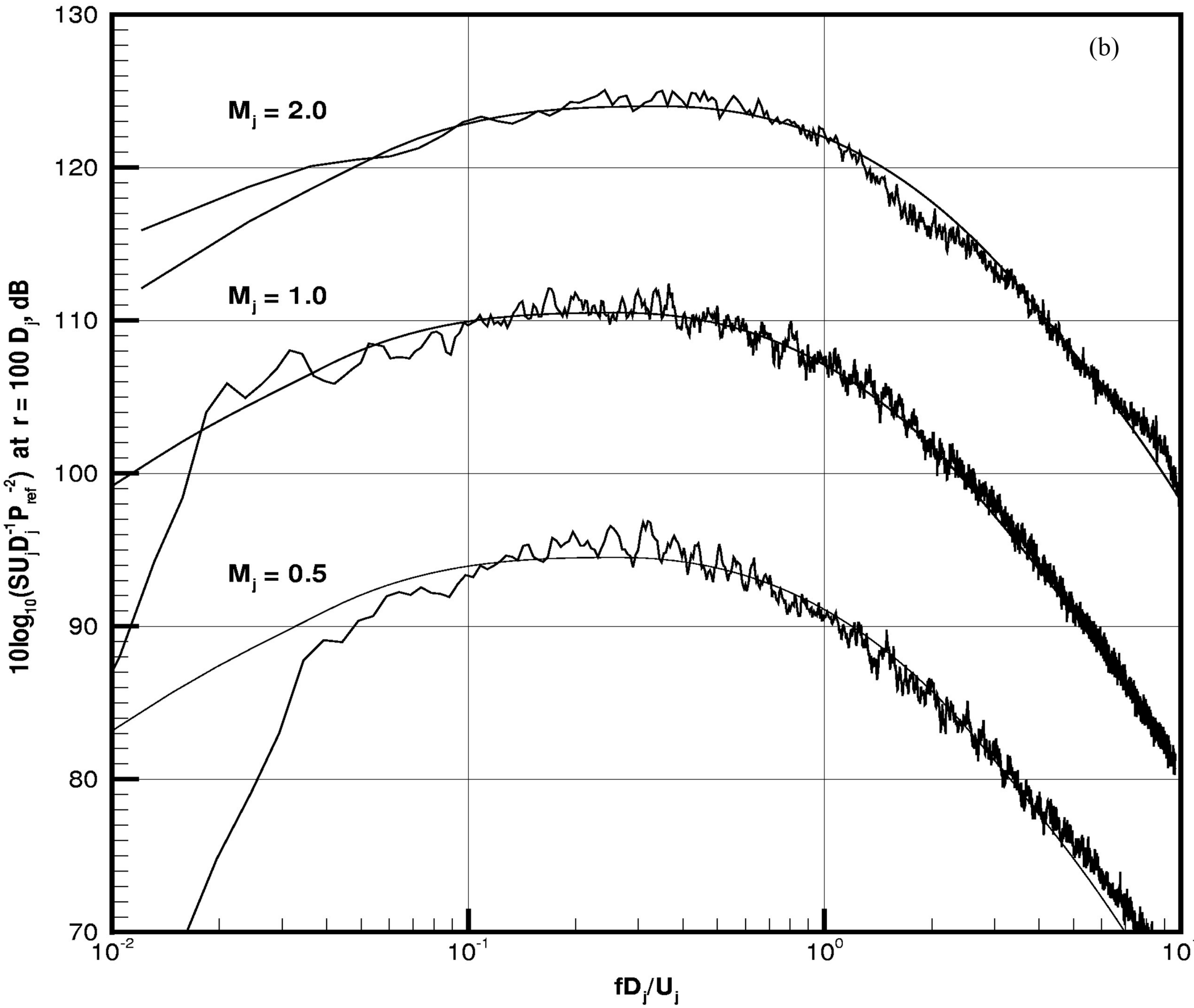




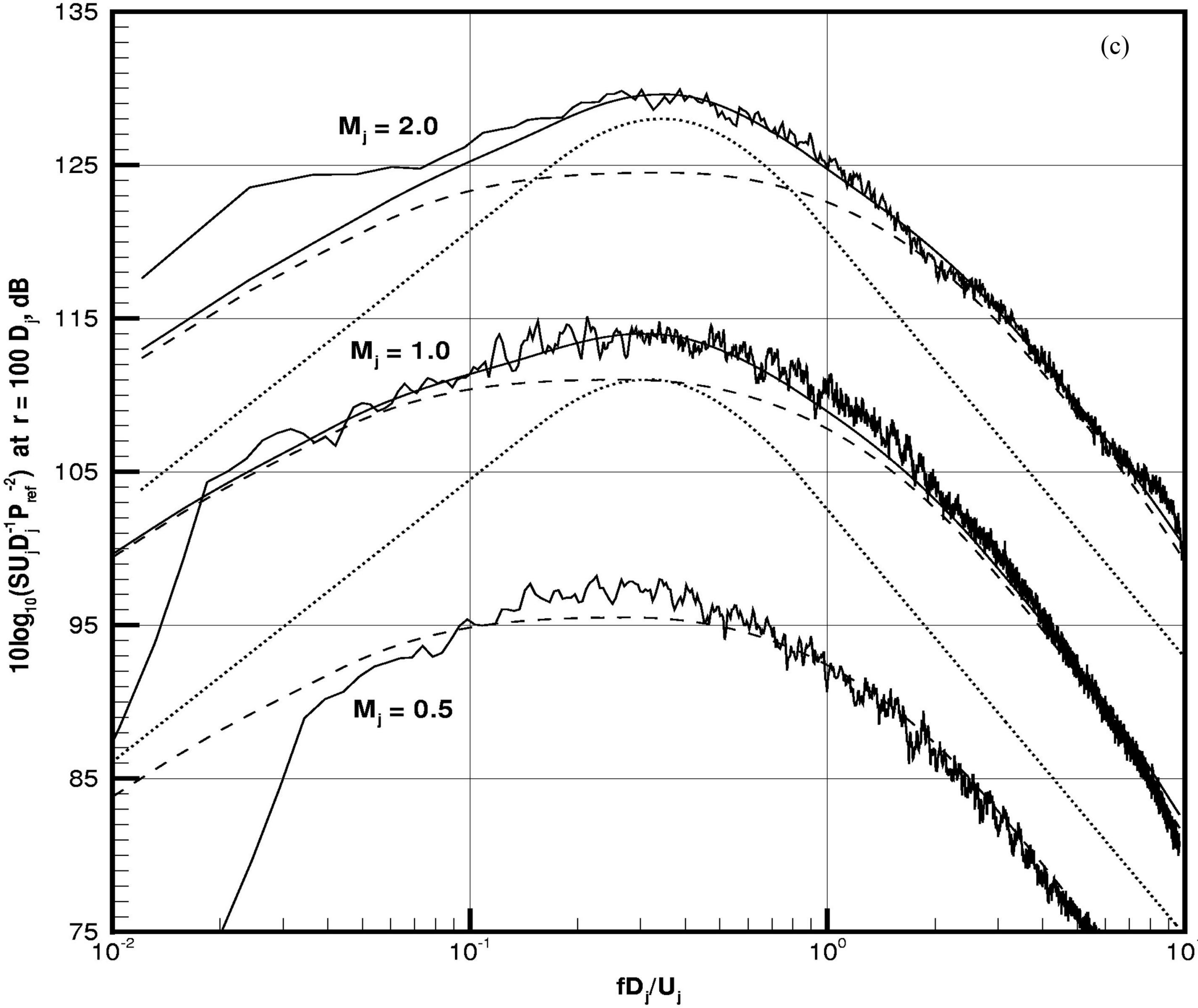
The two self-similar regions of a jet flow.
Both the mean flow and turbulence exhibit self similarity.



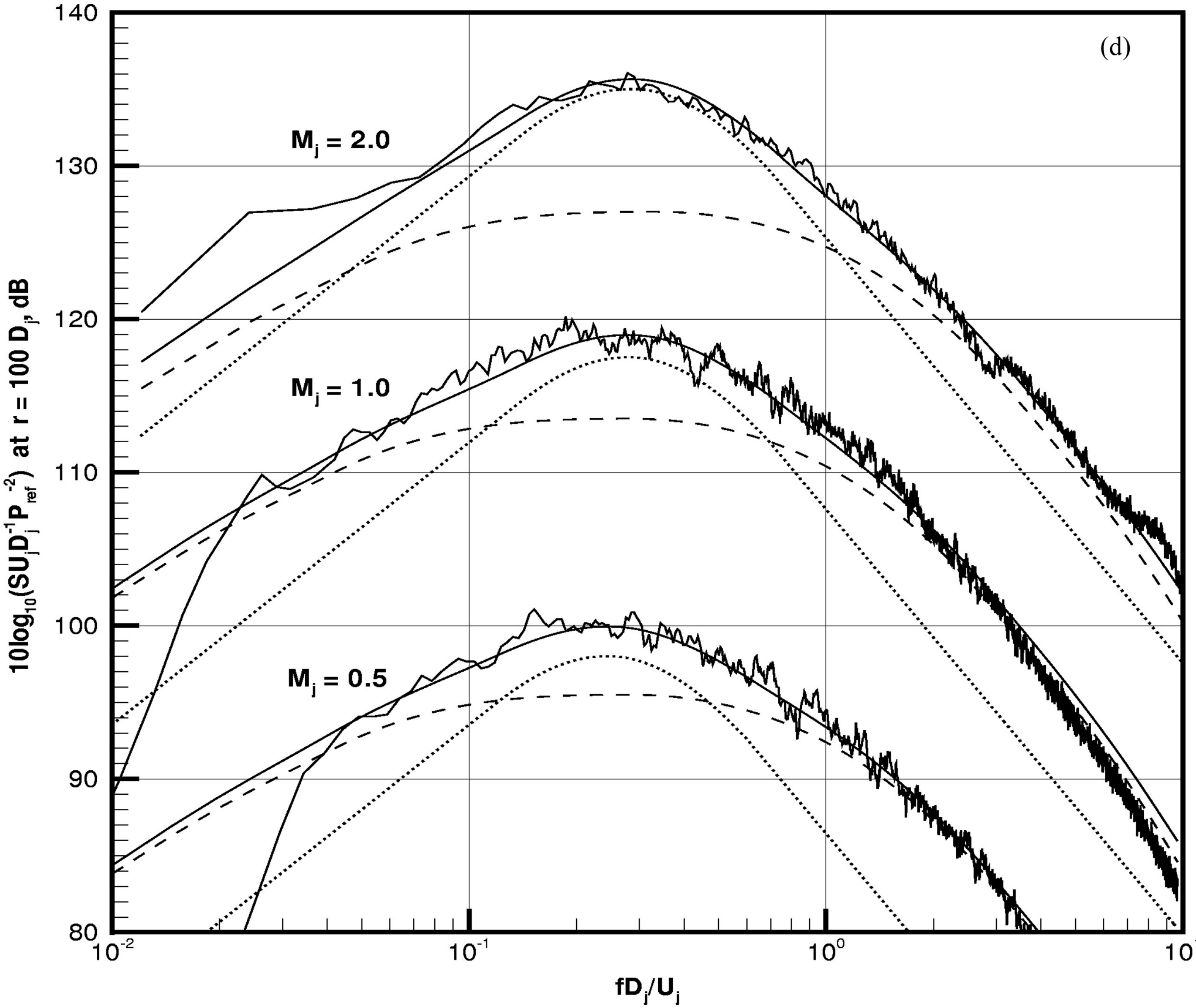
$T_r / T_a = 3.2$ Inlet angle = 90^0, Data from Seiner and Viswanathan



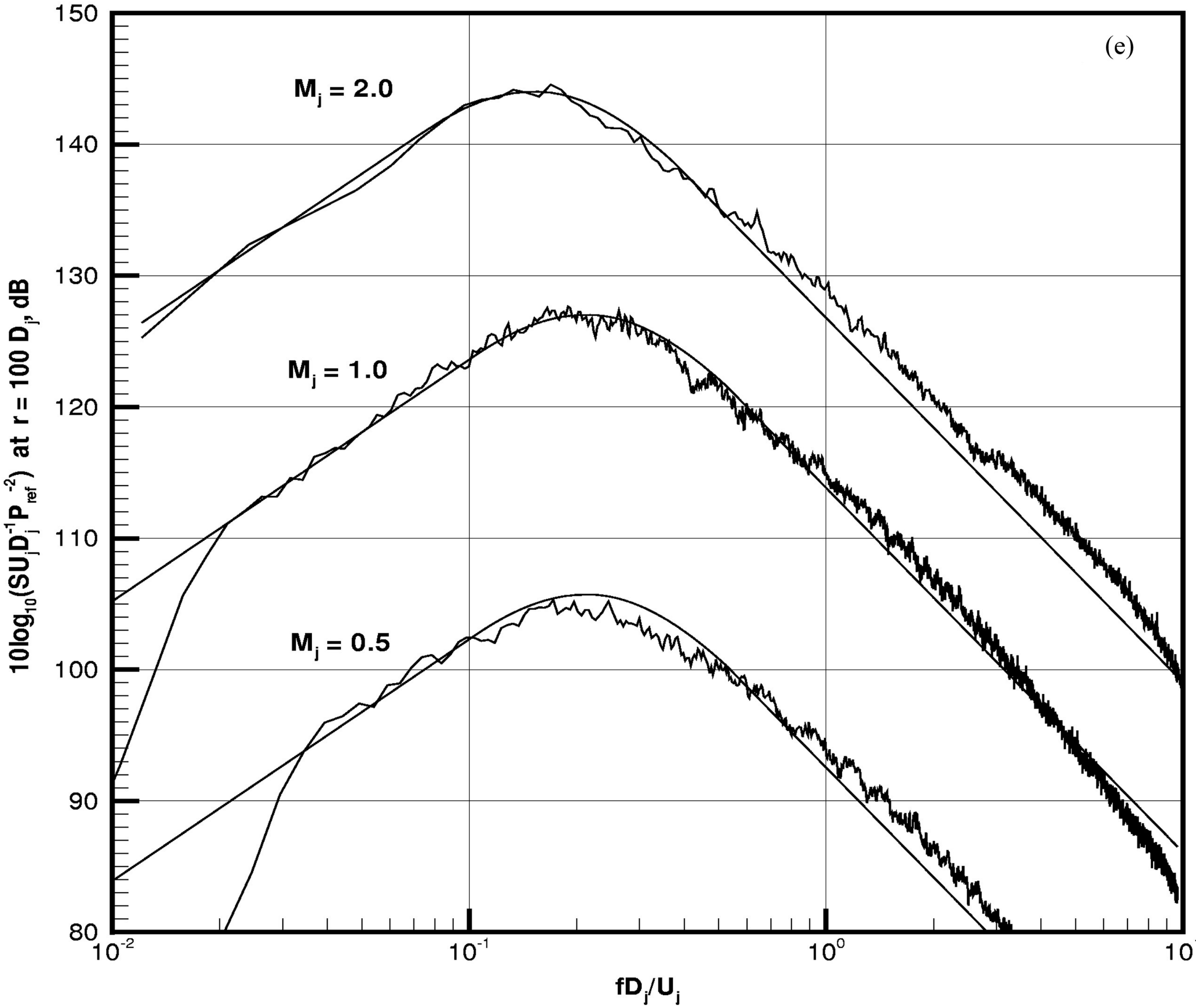
$T_r / T_a = 3.2$ Inlet angle = 100^0, Data from Seiner and Viswanathan



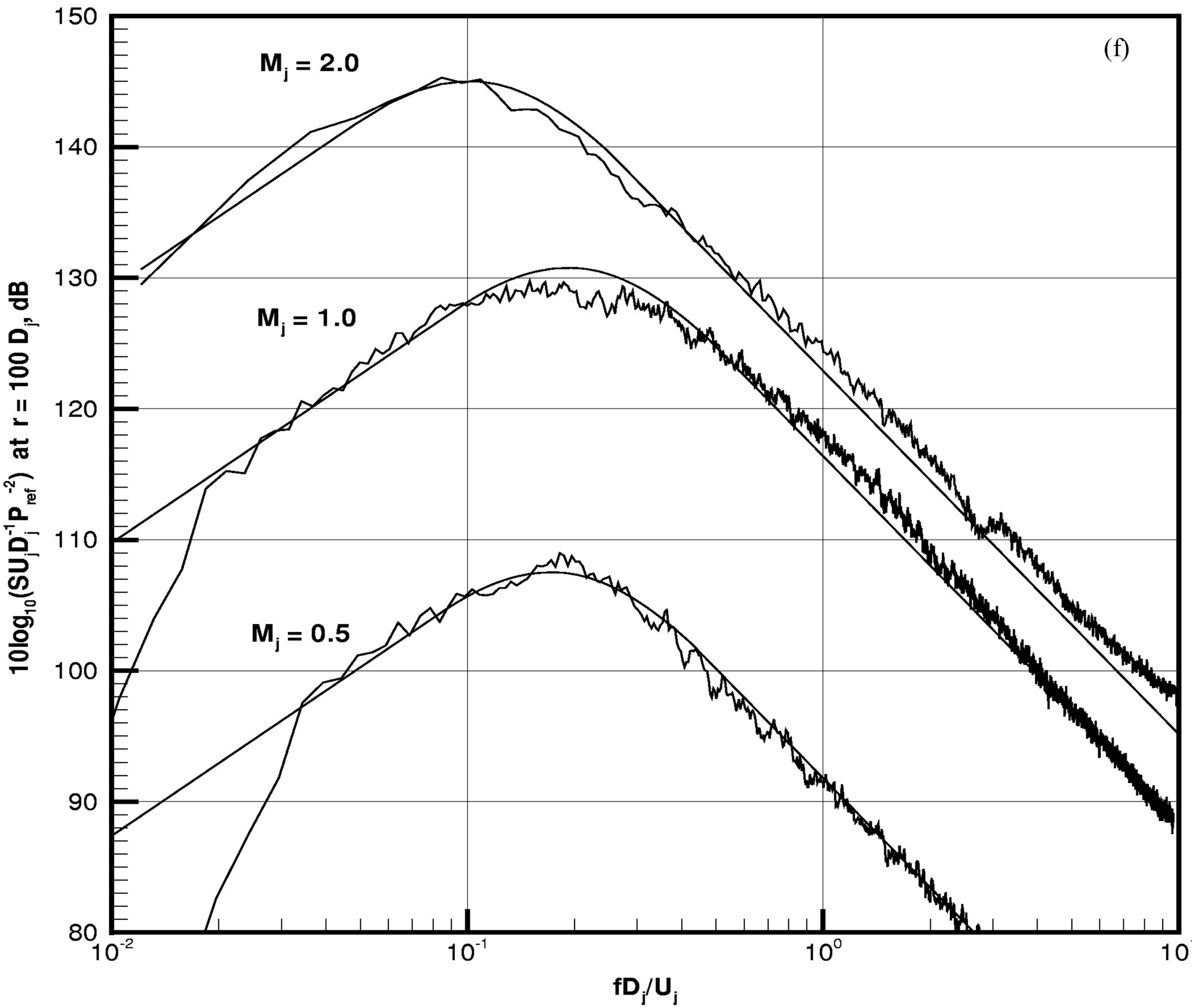
$T_r / T_a = 3.2$ Inlet angle = 110^0, Data from Seiner and Viswanathan



$T_r / T_a = 3.2$ Inlet angle = 120^0, Data from Seiner and Viswanathan



$T_r / T_a = 3.2$ Inlet angle = 130^0, Data from Seiner and Viswanathan



$T_r / T_a = 3.2$ Inlet angle = 140^0, Data from Seiner and Viswanathan

Summary

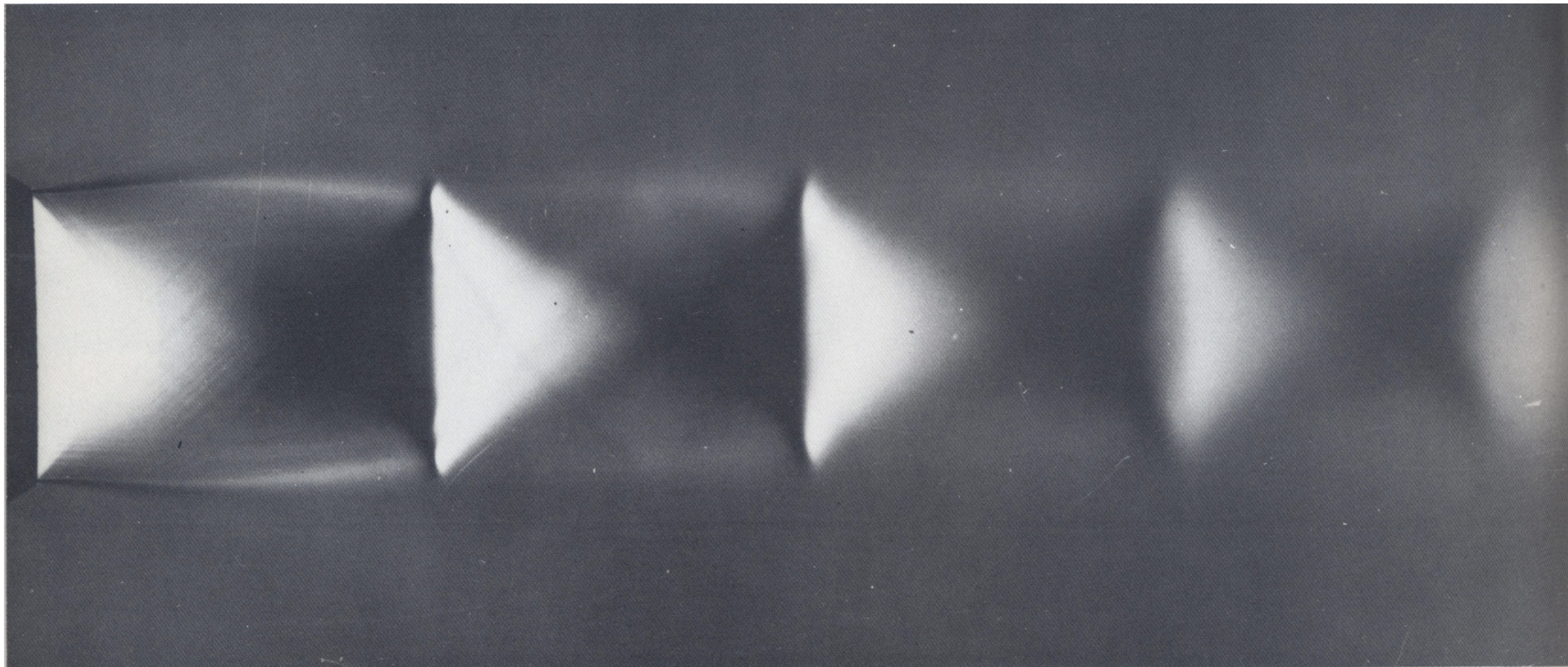
Characteristics of turbulence mixing noise of laboratory jets

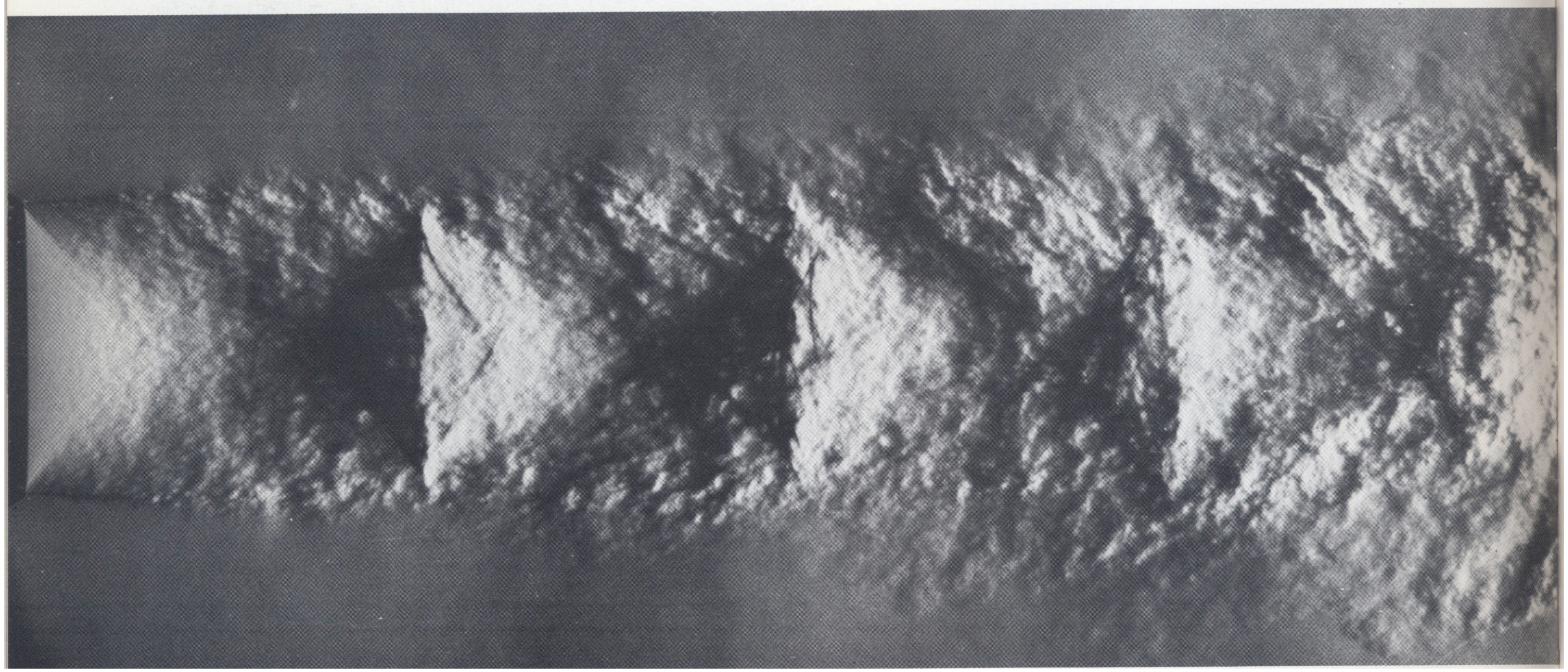
1. Noise spectrum has a single peak, even though there are two dominant noise components.

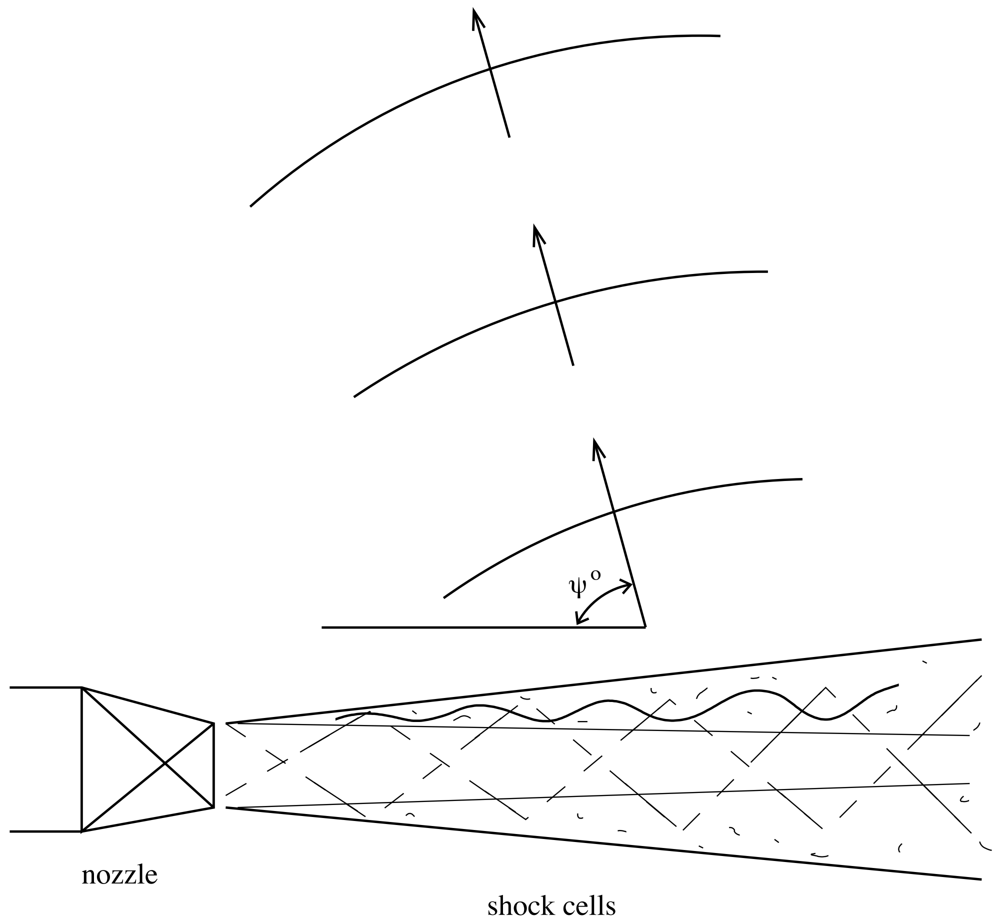
2. Change of dominancy of the two noise components takes place in the angular sector of 105 deg to 125 deg.

3. At 130 deg and 140 deg. the noise spectrum is totally dominated by the noise of the large turbulence structures of the jet flow.

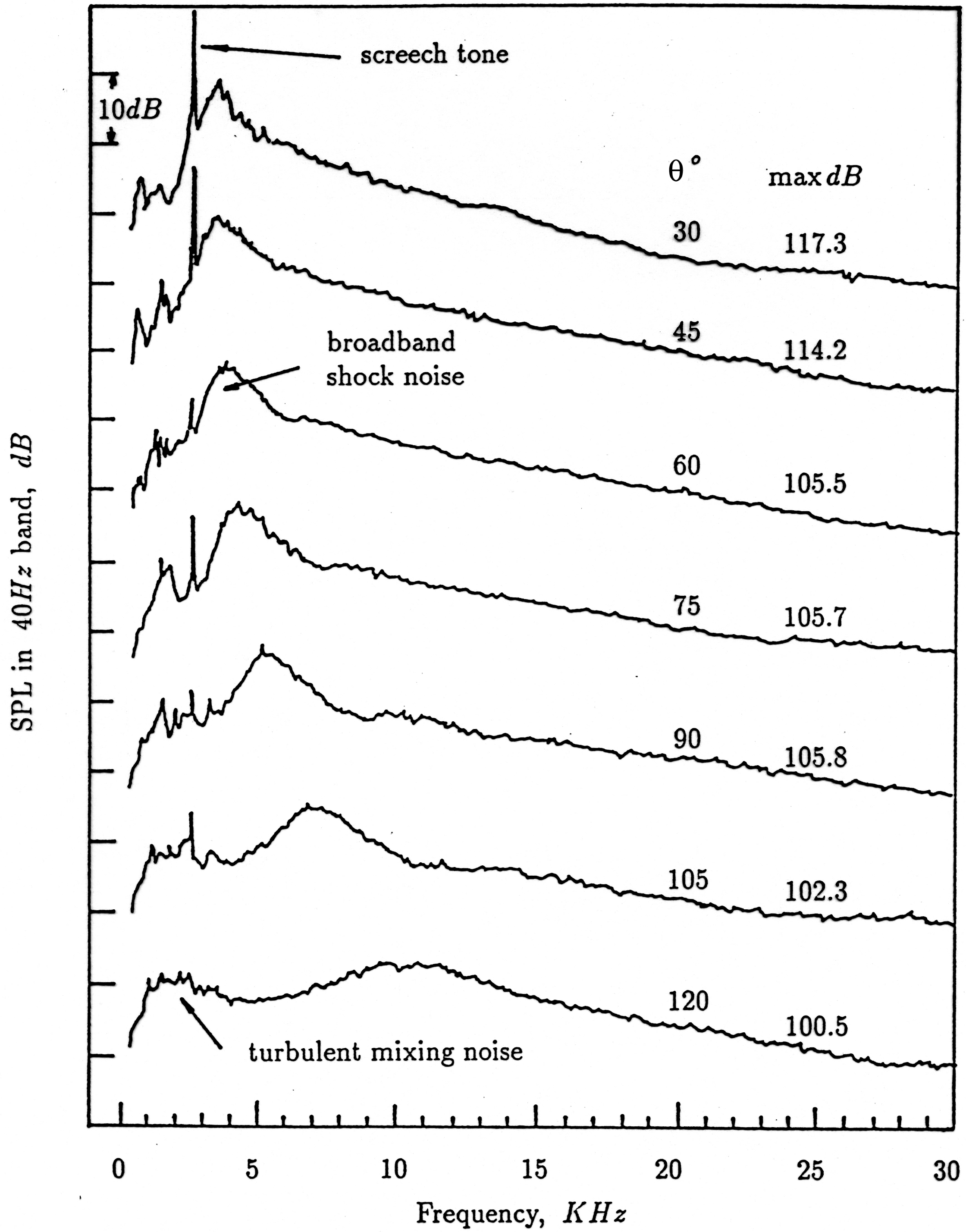
4. At inlet angle less than 105 deg. The noise spectrum is dominated by fine scale turbulence noise.







Generation of broadband shock cell noise by the scattering of instability waves/large turbulence structures by the quasi-periodic shock cell structure in the jet plume



$M_j = 1.67$

$M_d = 1.5$ (nozzle design Mach number

Cold jet

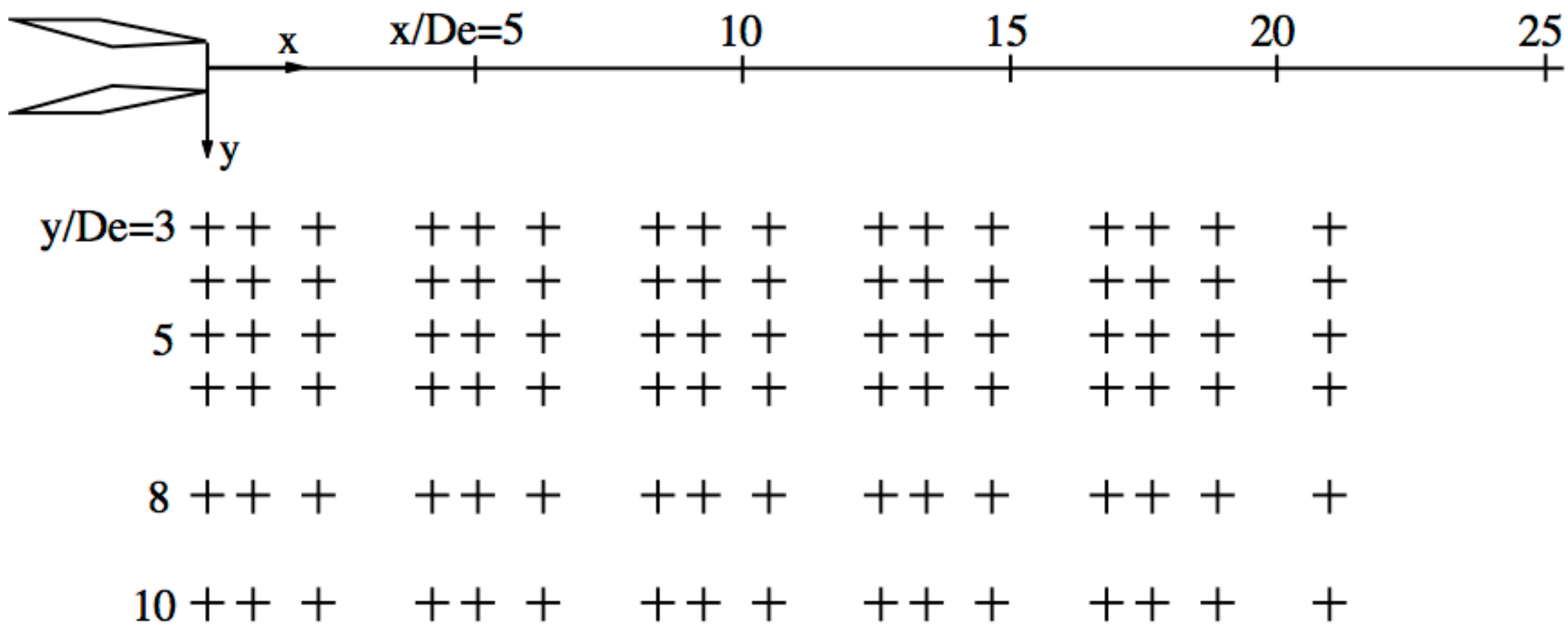
Data from Norum and Seiner

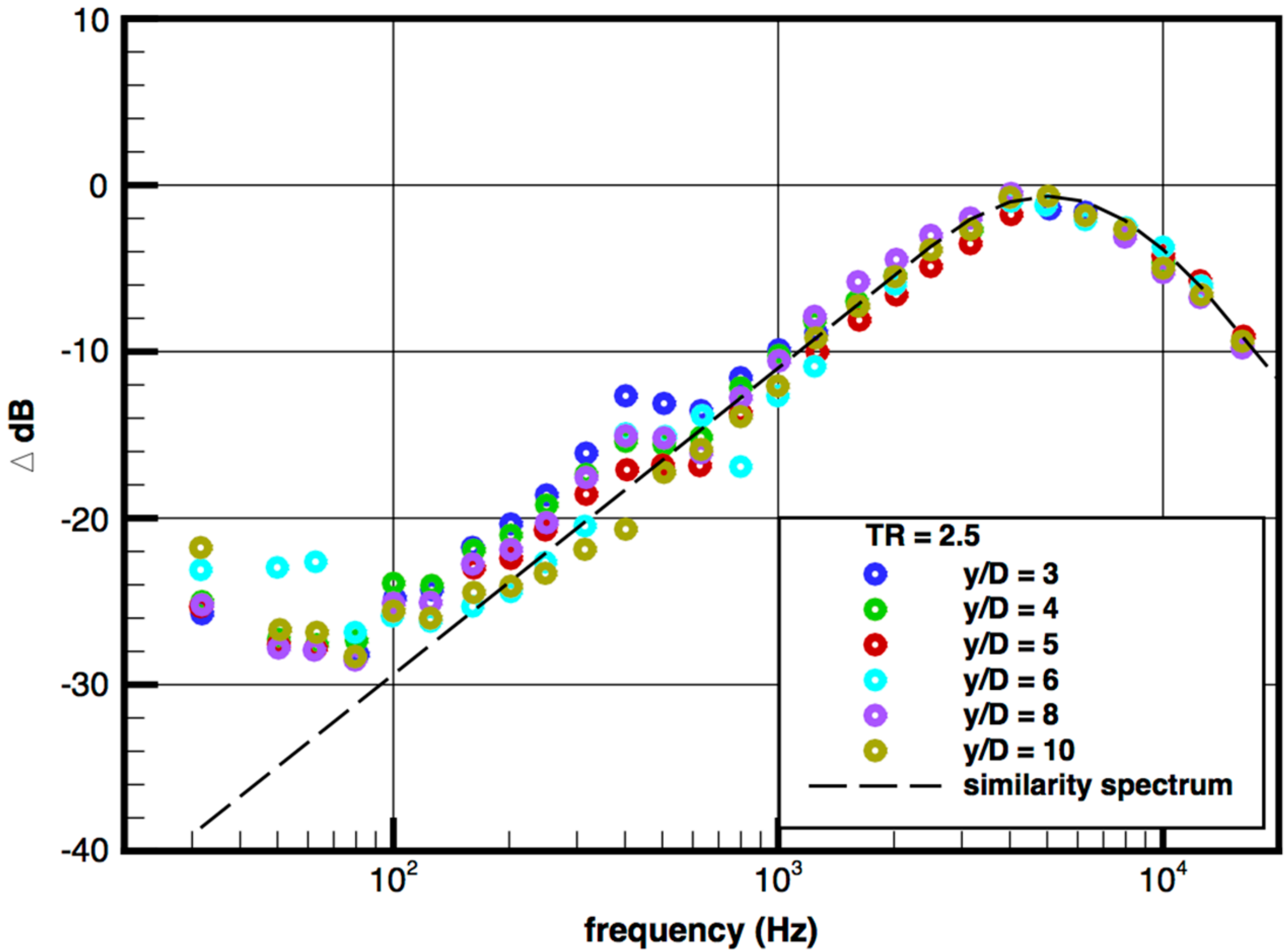
Applicability of far field similarity spectra to the near noise field of high-speed jets.

B. Greska, A. Krothapally, W. C. Horne, and N. Burnside,
“A Near-Field Study of High Temperature Supersonic Jets”,
AIAA Paper 2008-3026.

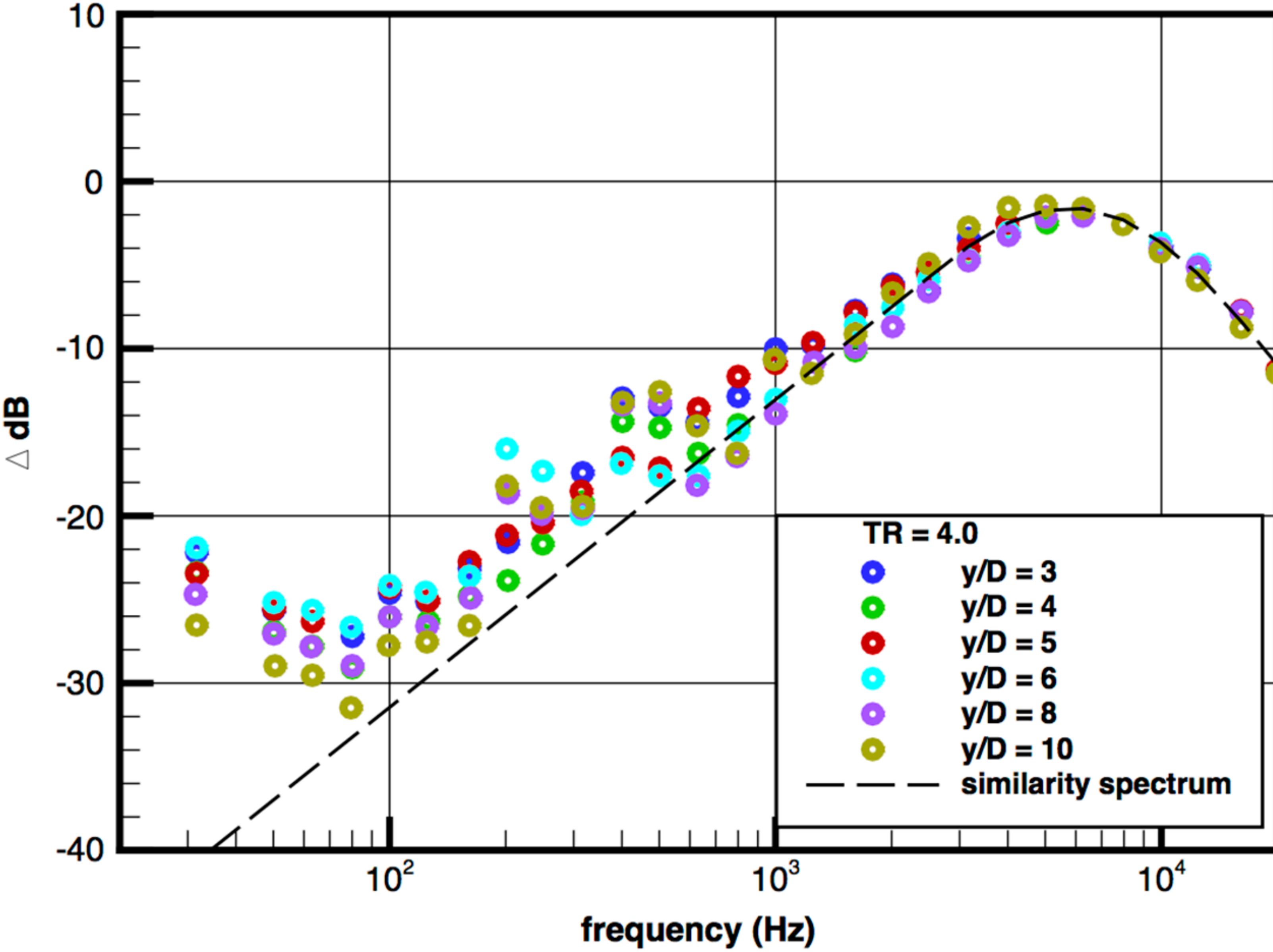
Greska et al performed extensive measurements of the near field noise of high temperature supersonic jets. We wish to use their data to demonstrate that the far field similarity spectra also fit the measured near field spectra

Coordinates of near field noise measurements

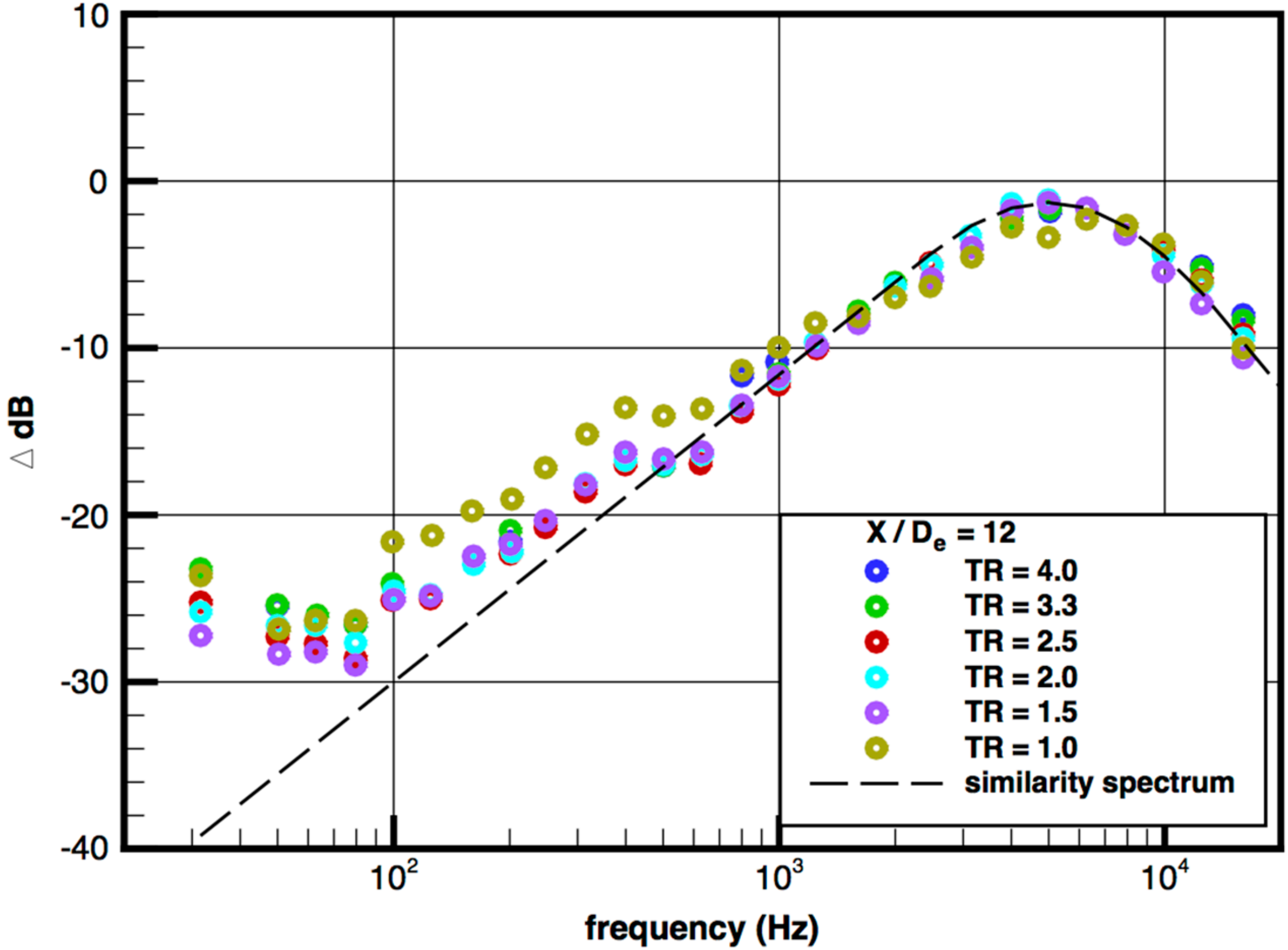




M=2.0, data measured in the direction of maximum noise radiation



M=2.0, data measured in the direction of maximum noise radiation



M=2.0, data measured in the direction of maximum noise radiation

Similarity spectra appear to work for near field noise of hot supersonic jets as well.

Let's apply the similarity spectra to the near field noise of solid propellant rocket.

Summary – far field noise from laboratory jets

There are two dominant components of turbulence mixing noise.

1. Large turbulence structures noise – dominant from 0 deg to 50 deg (exhaust angle).
2. Fine scale turbulence noise – dominant from 70 to 80 deg to 180 deg.
3. Both components are dominant between 55 to 75 deg.

In the far field, jet noise can be regarded to radiate from a point source. This cannot be so in the near field. So it is necessary to consider the region of dominance of each noise component in the near field.

We will analyze near field rocket noise in **two** steps

1. We will first demonstrate that the near noise field of a solid propellant rocket has two dominant noise components just as those of a hot supersonic jet.

2. We will then investigate the region of dominance of each of the two noise components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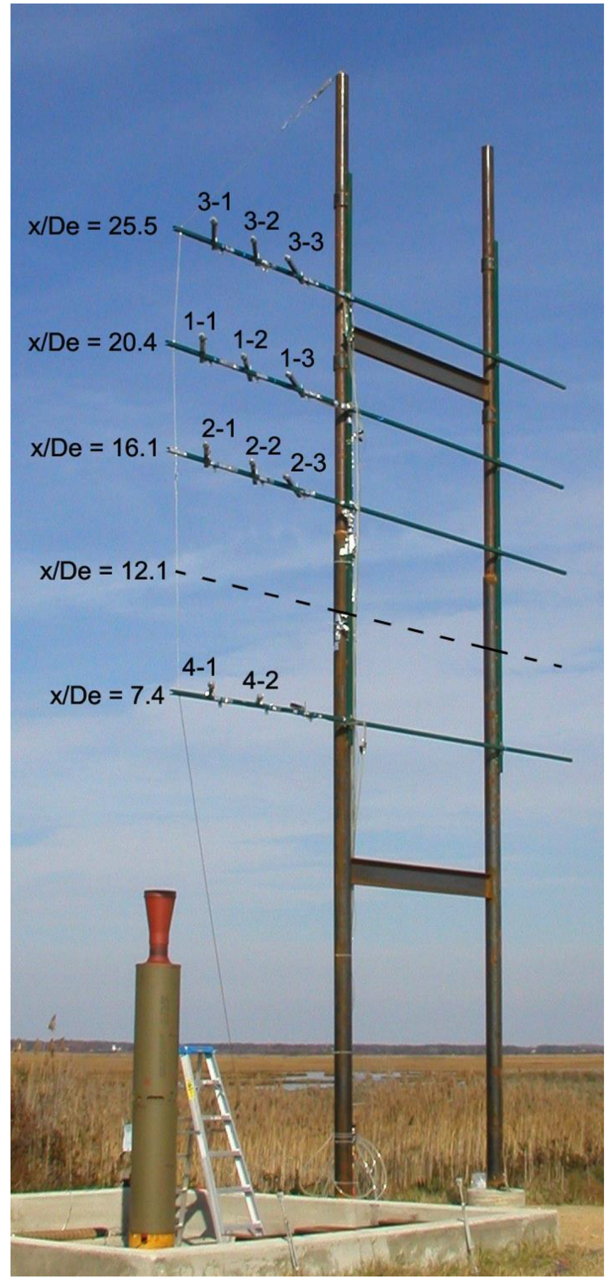
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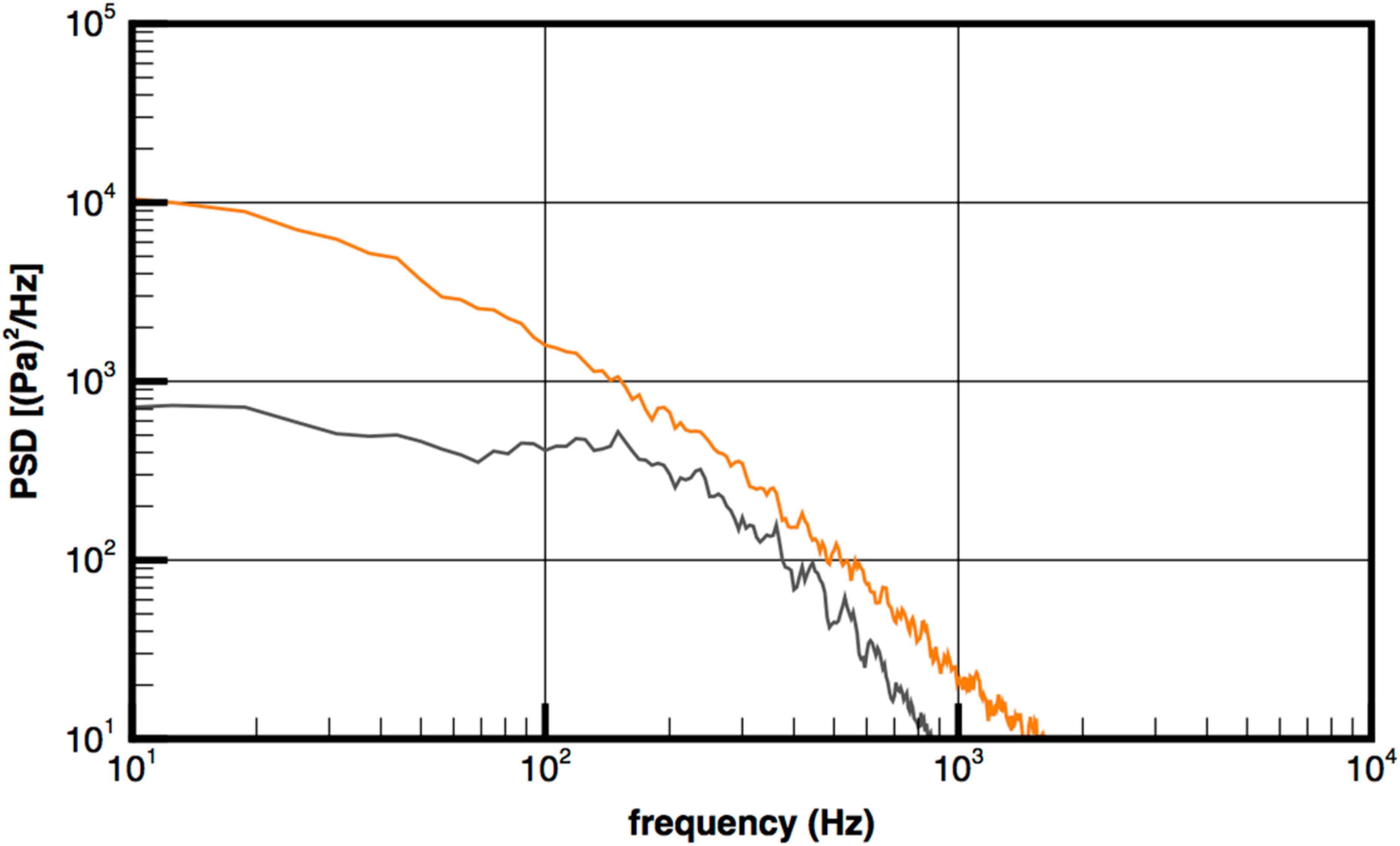
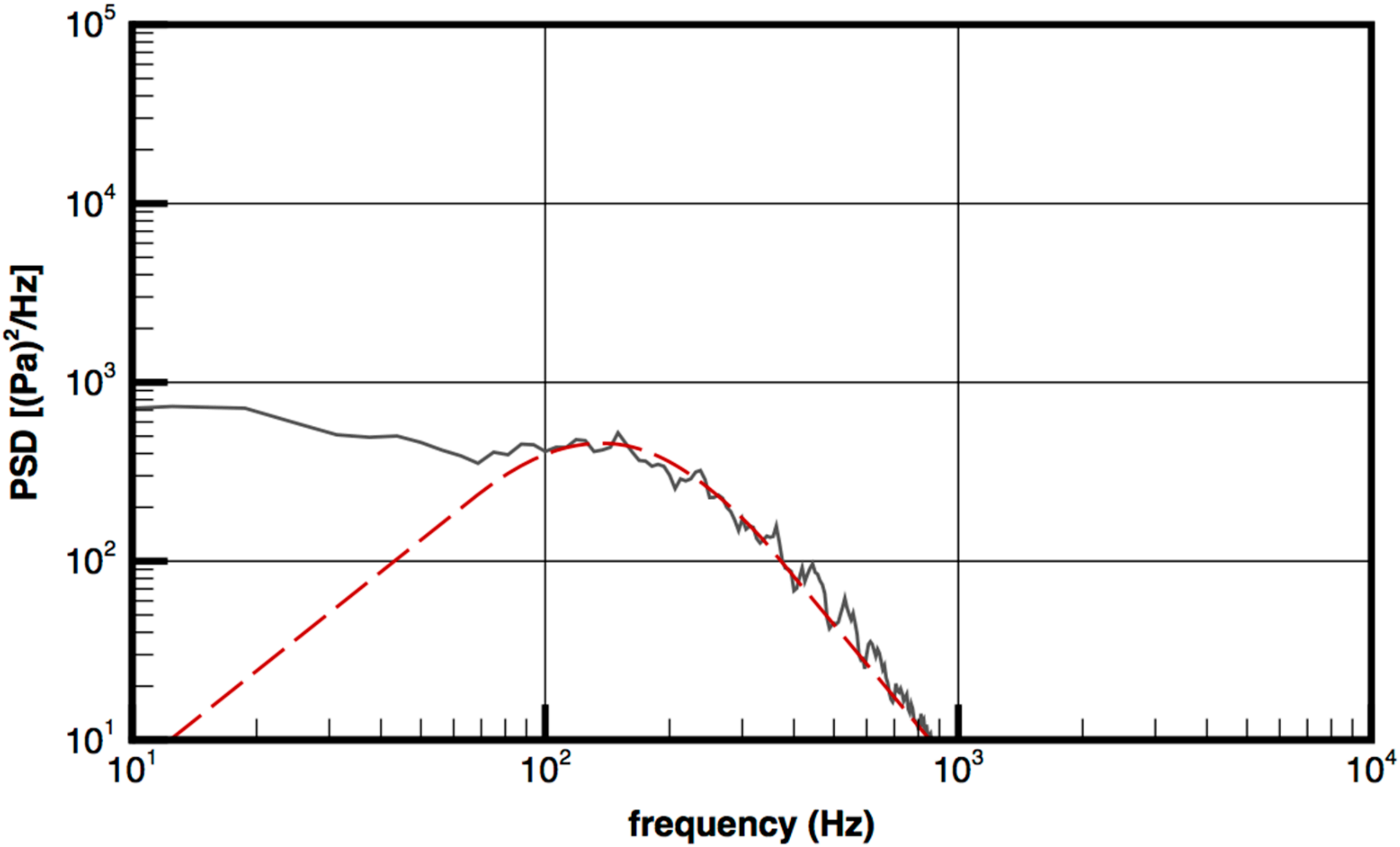
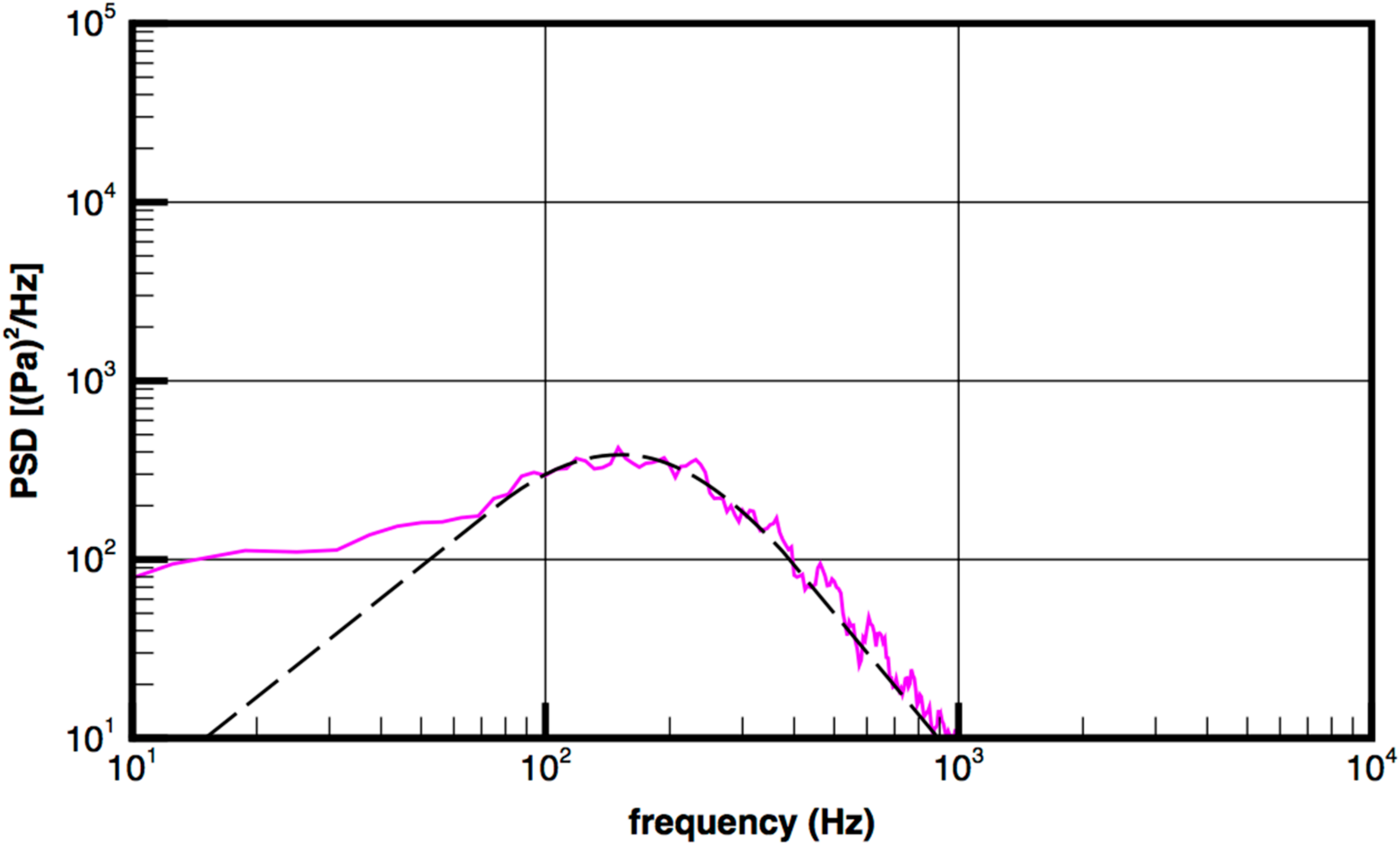
3-1
3-2
3-3
x/De = 20.4
1-1
1-2
1-3
x/De = 16.1
2-1
2-2
2-3
x/De = 12.1
x/De = 7.4
4-1
4-2



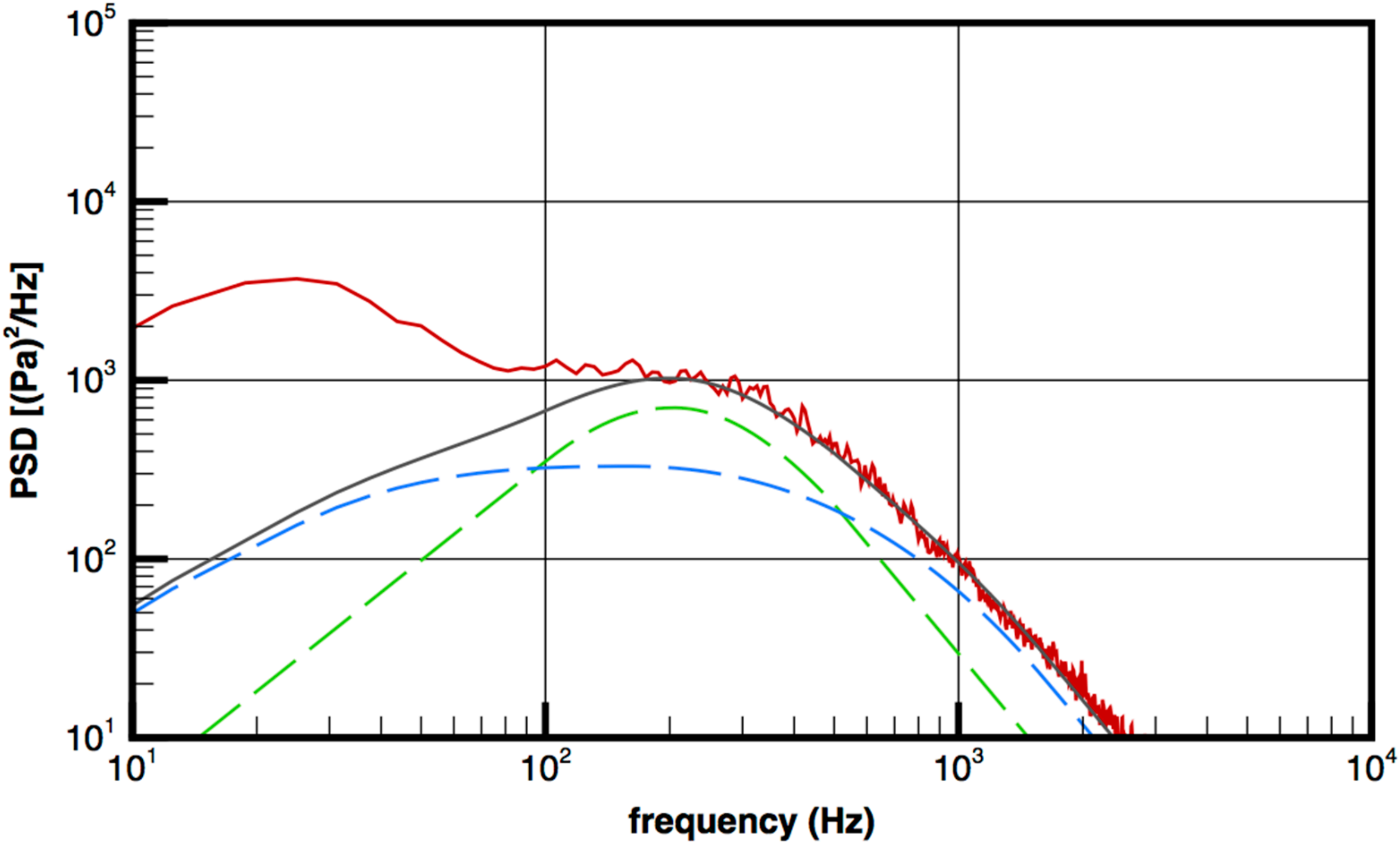
x/D = 25.5, r/D = 4.38, low burn



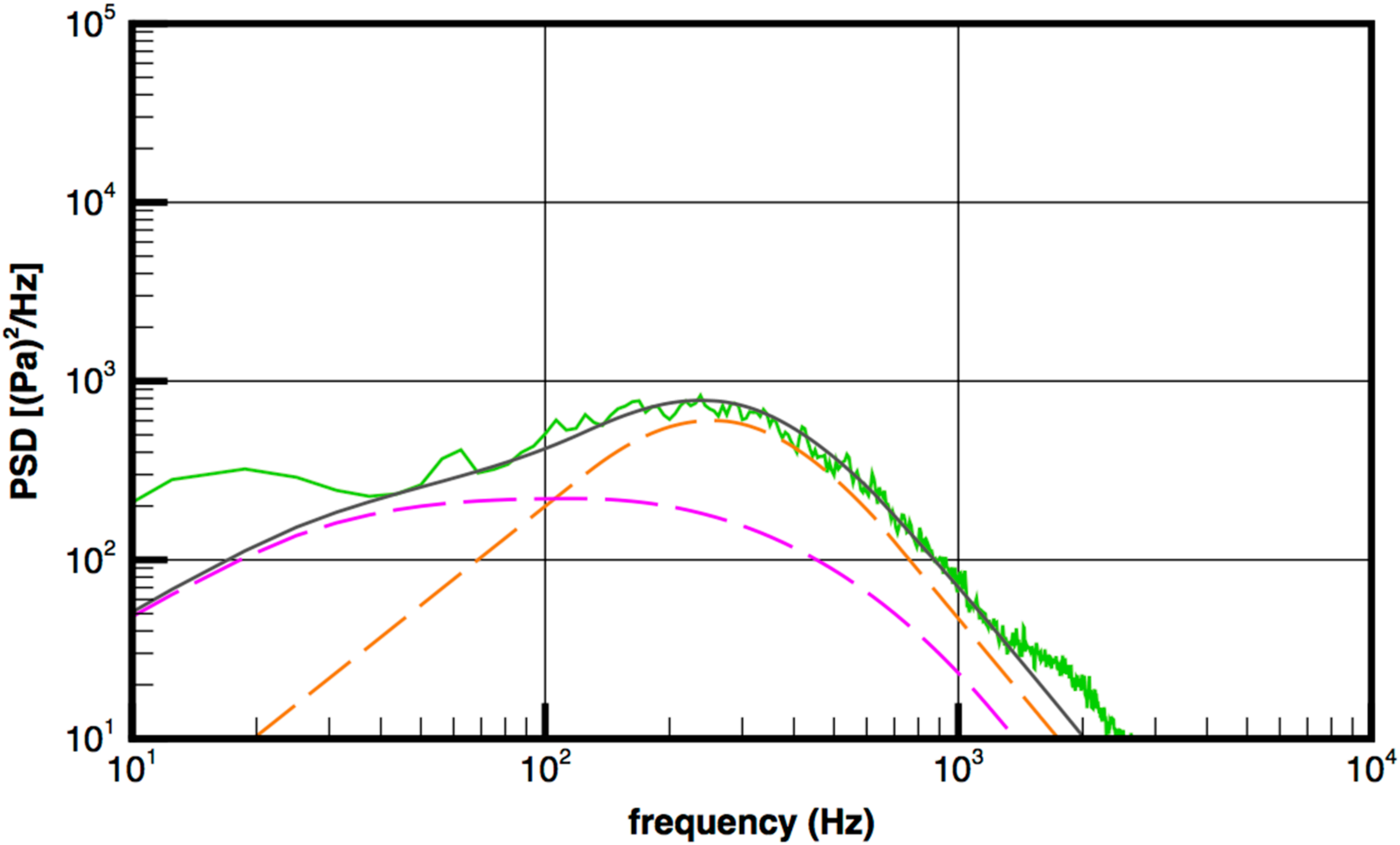
x/D = 25.5, r/D = 6.51, low burn



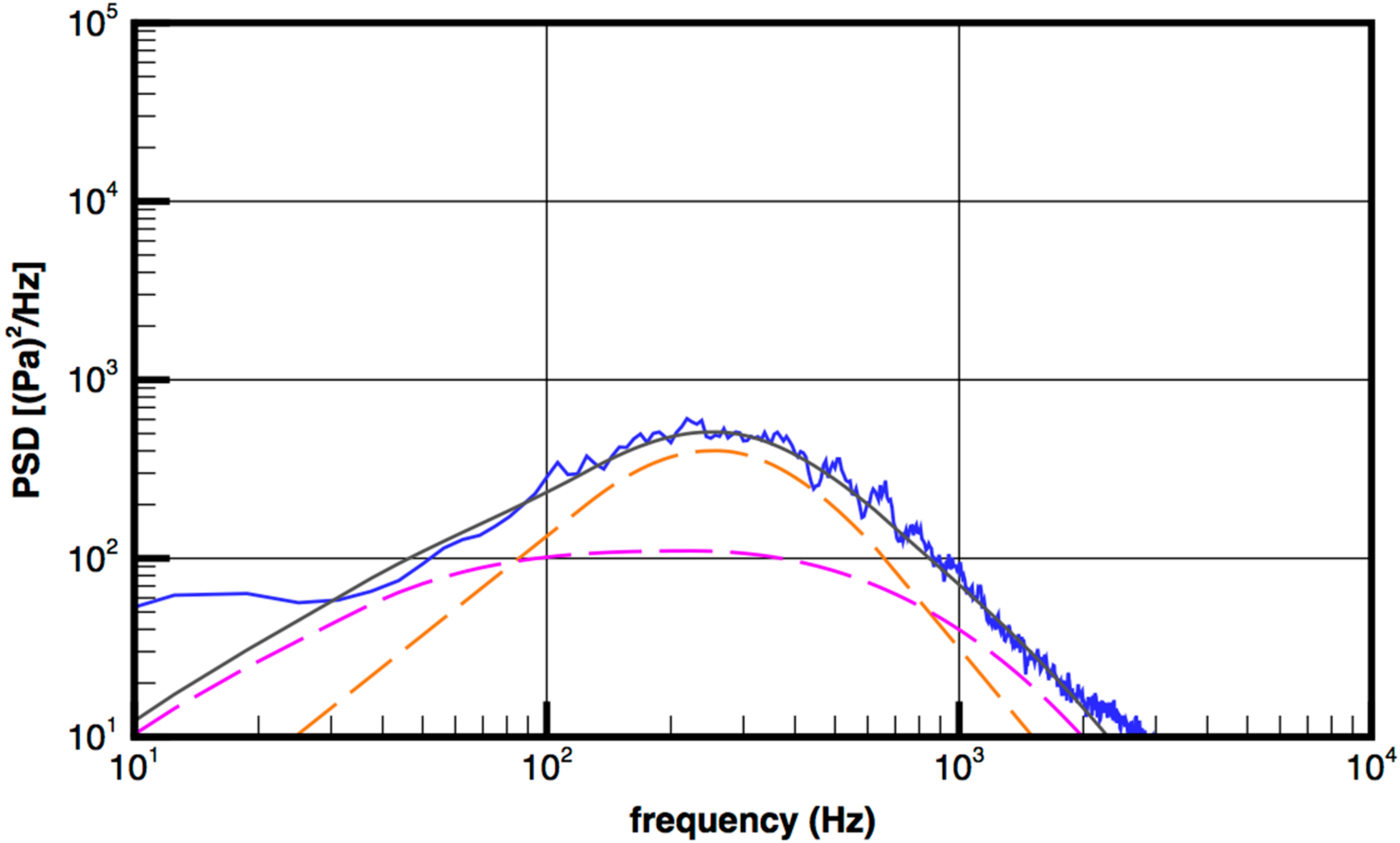
x/D = 25.5, r/D = 8.62, low burn



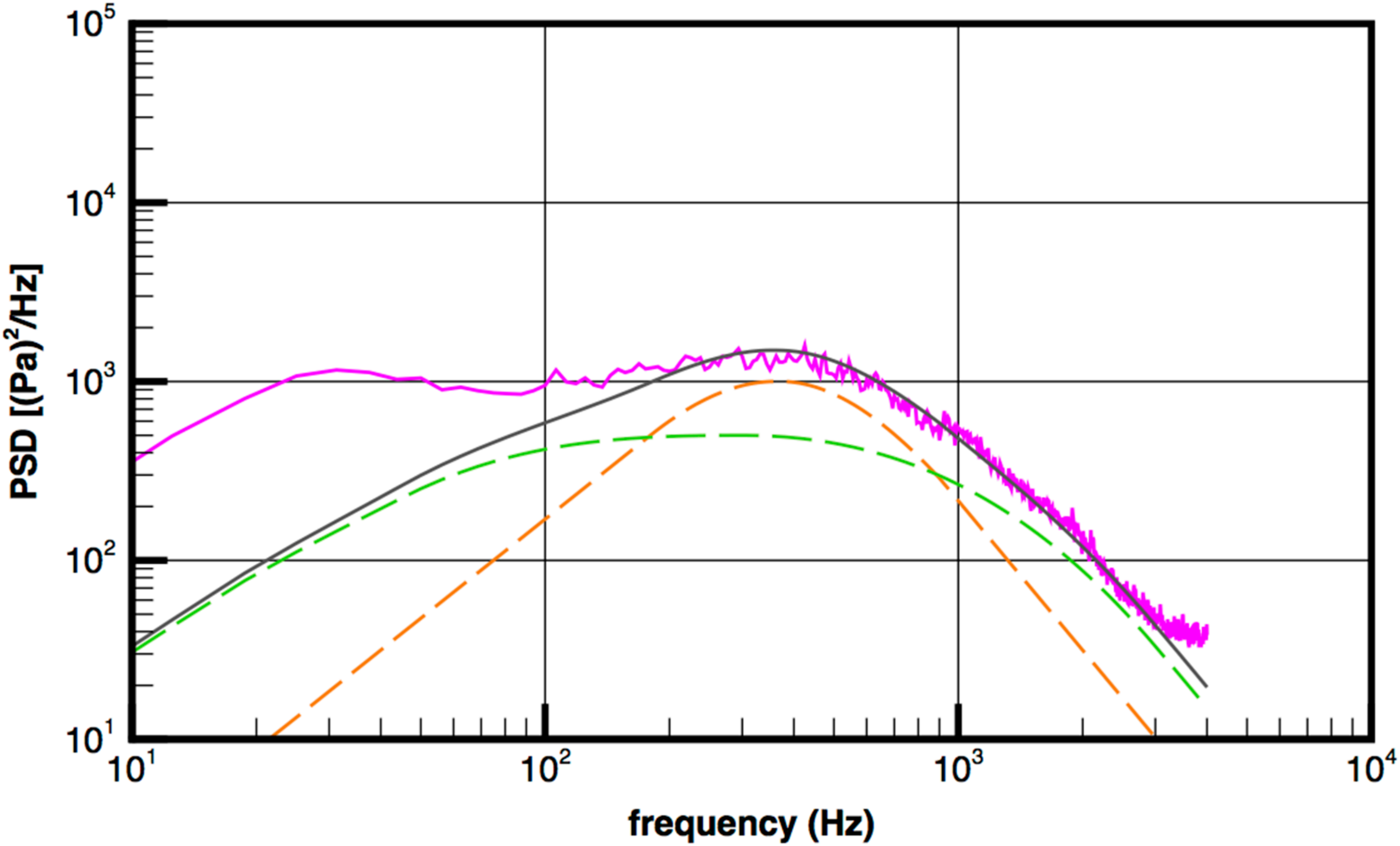
x/D = 20.4, r/D = 4.32, low burn



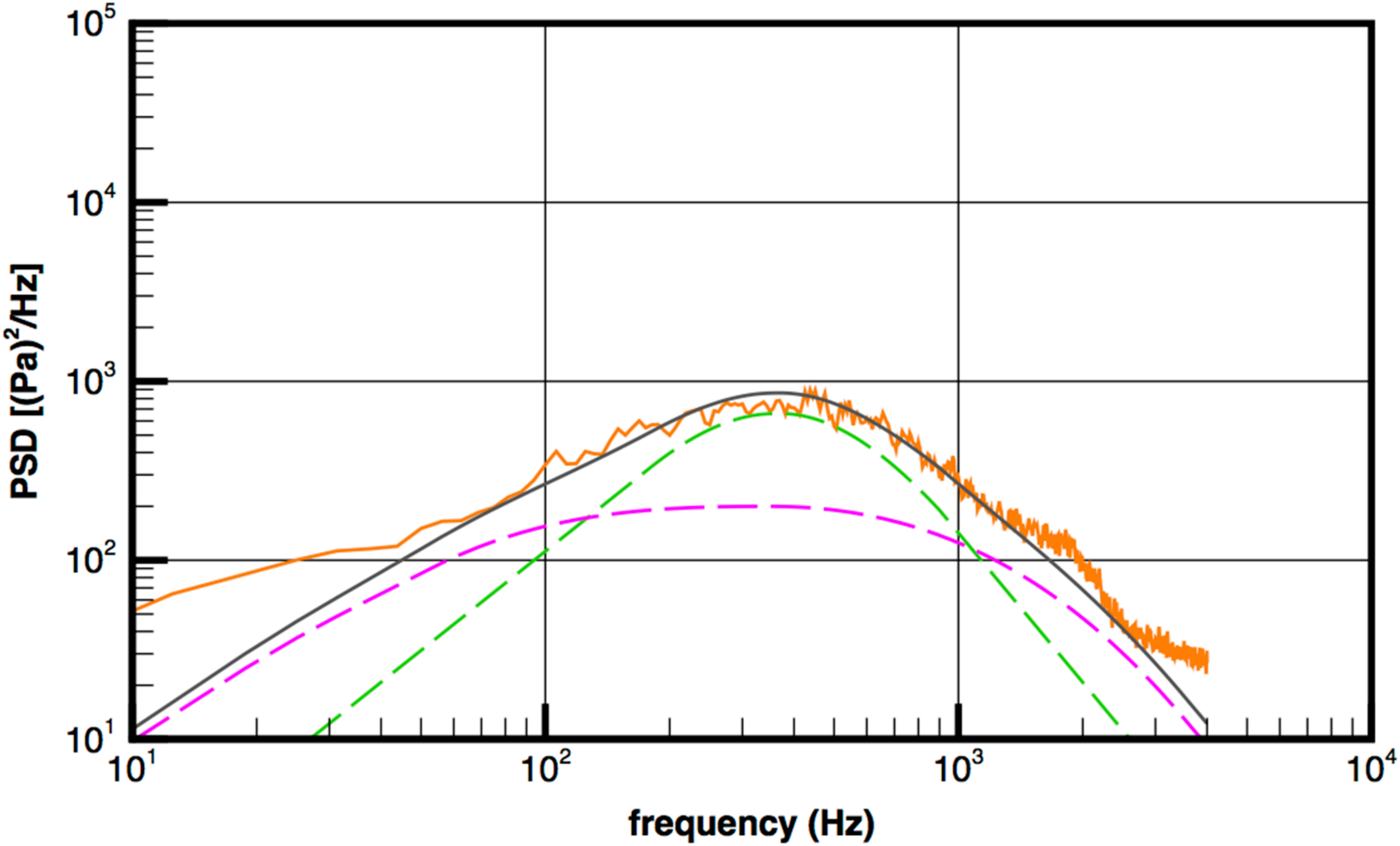
x/D = 20.4, r/D = 6.51, low burn



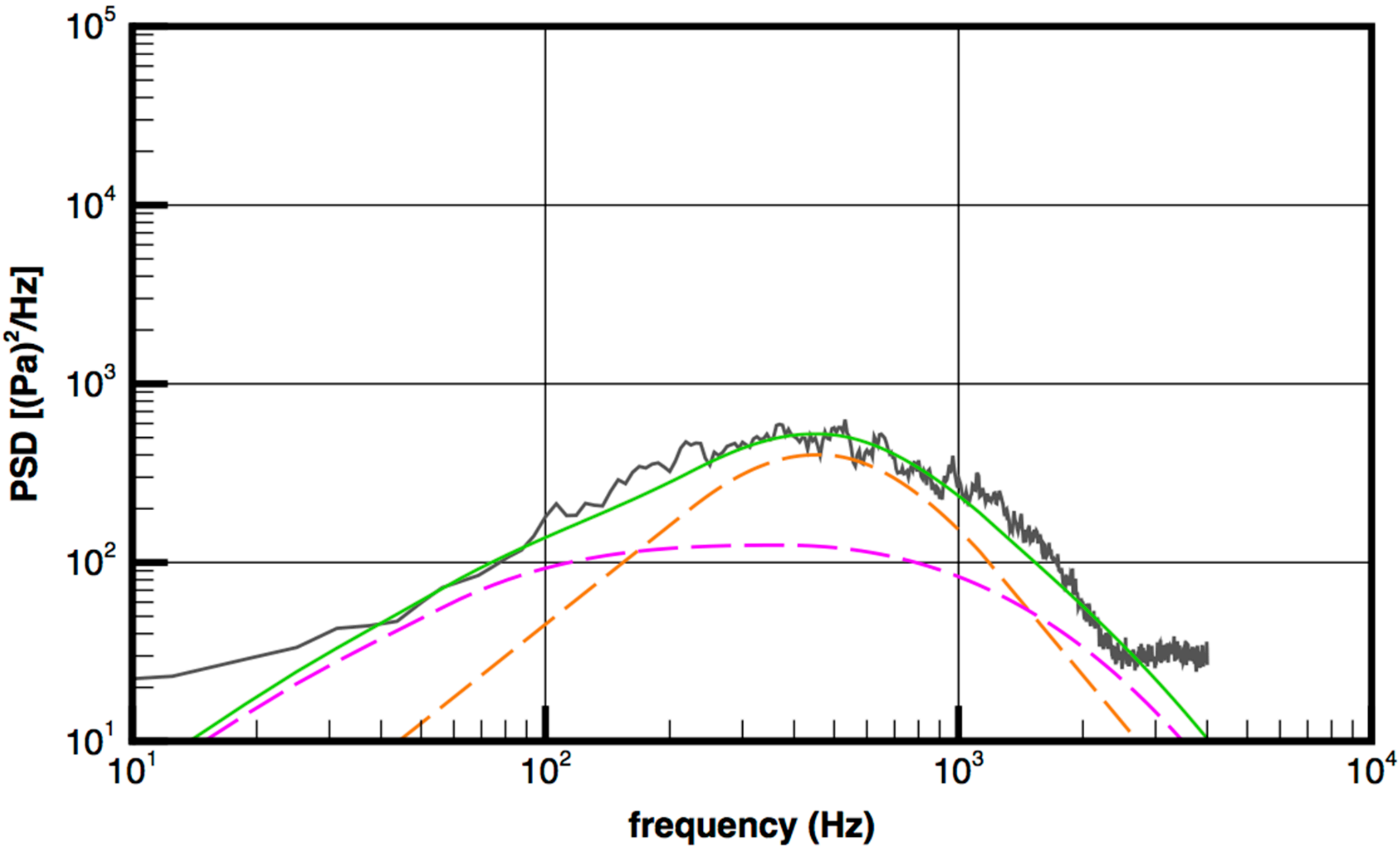
x/D = 20.4, r/D = 8.86, low burn



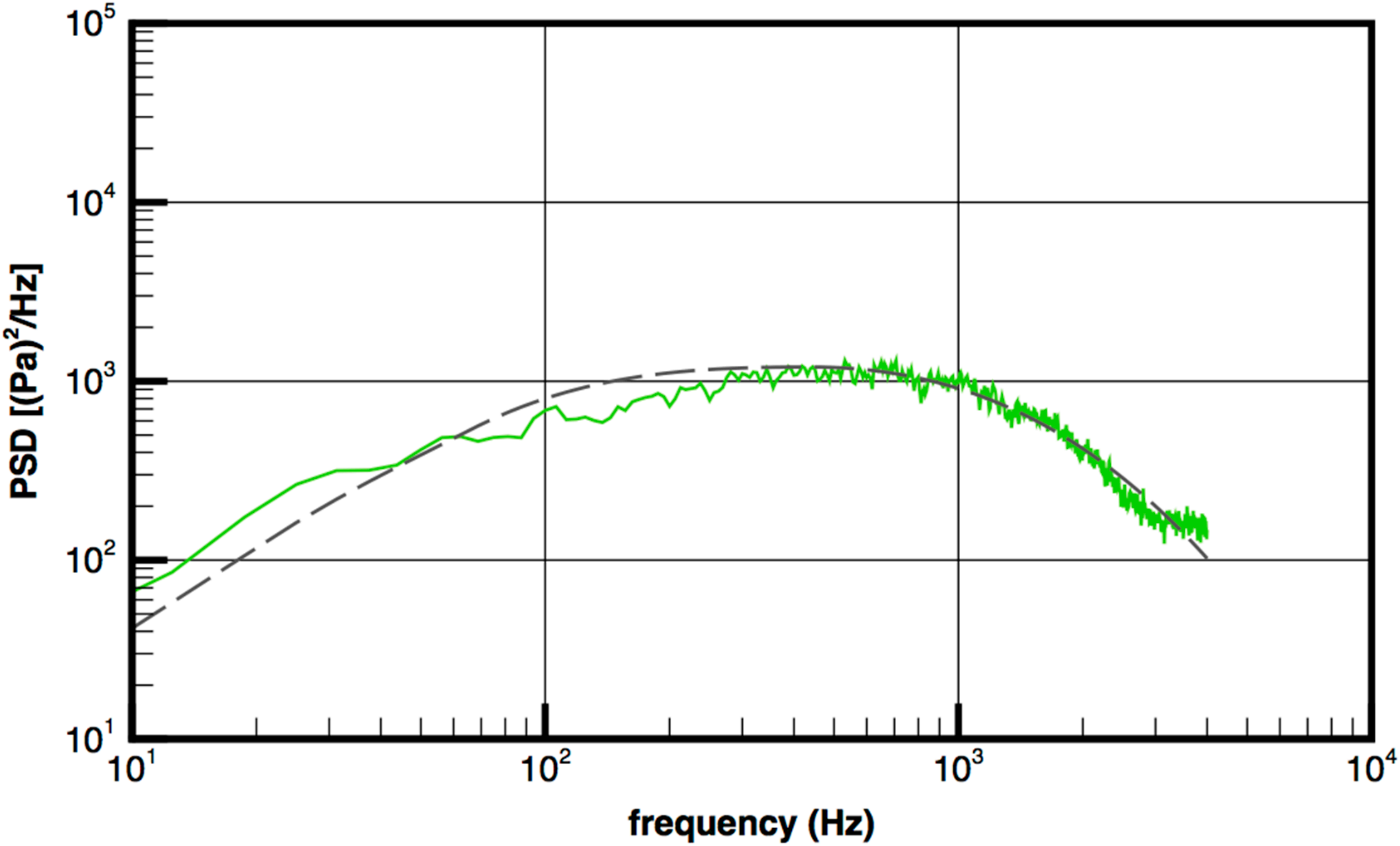
x/D = 16.2, r/D = 4.43, low burn



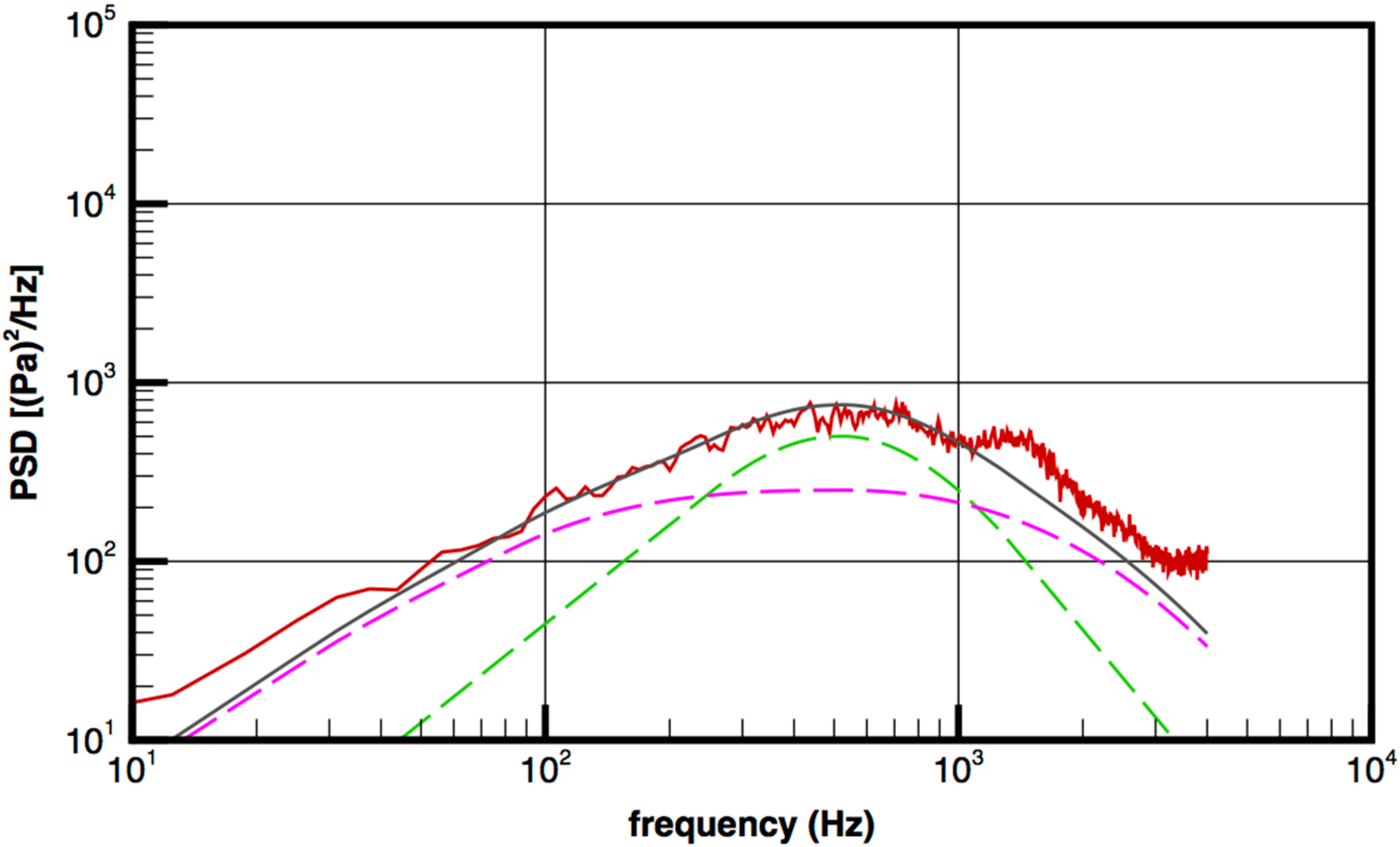
x/D = 16.2, r/D = 6.79, low burn



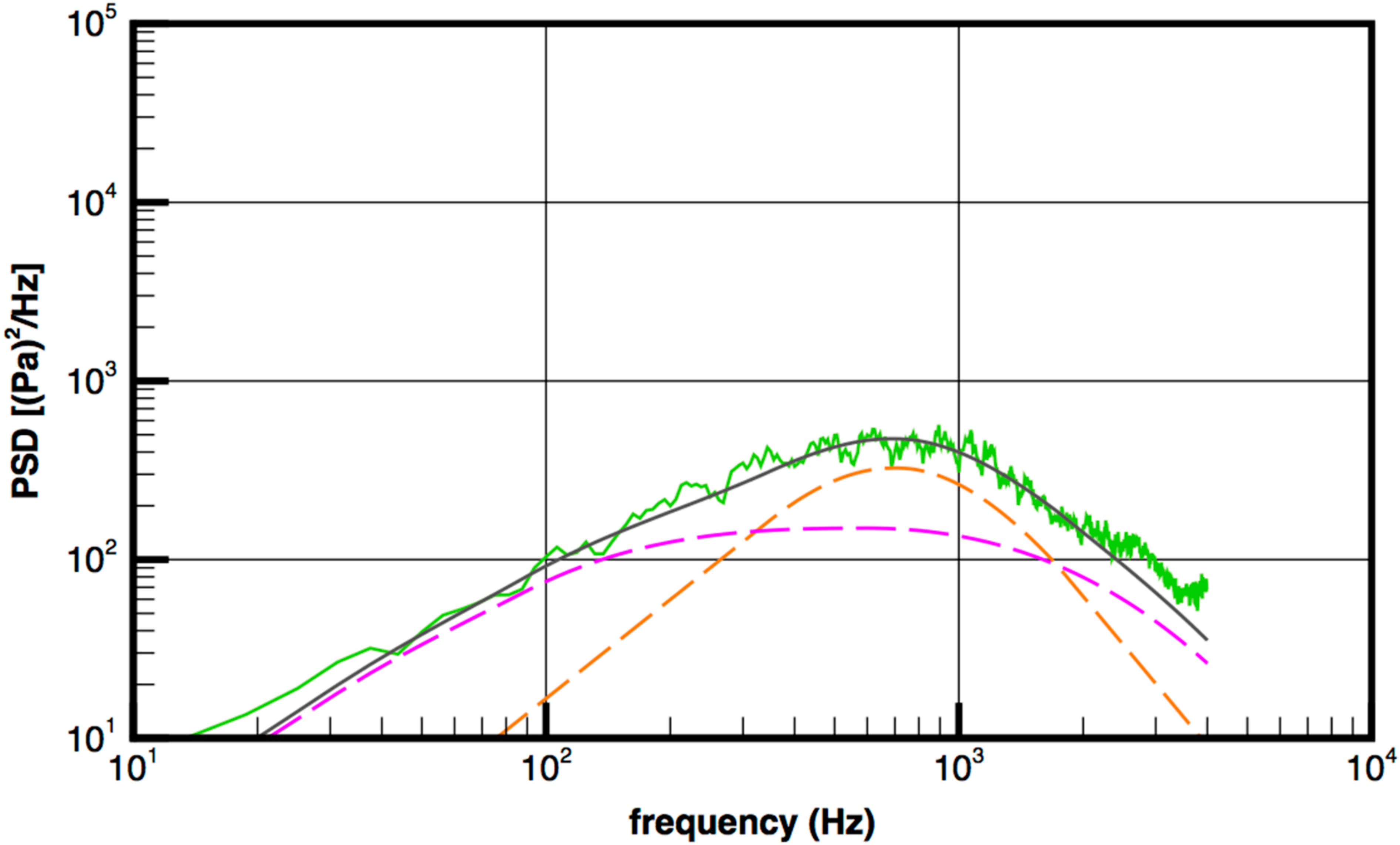
x/D = 16.2, r/D = 8.86, low burn



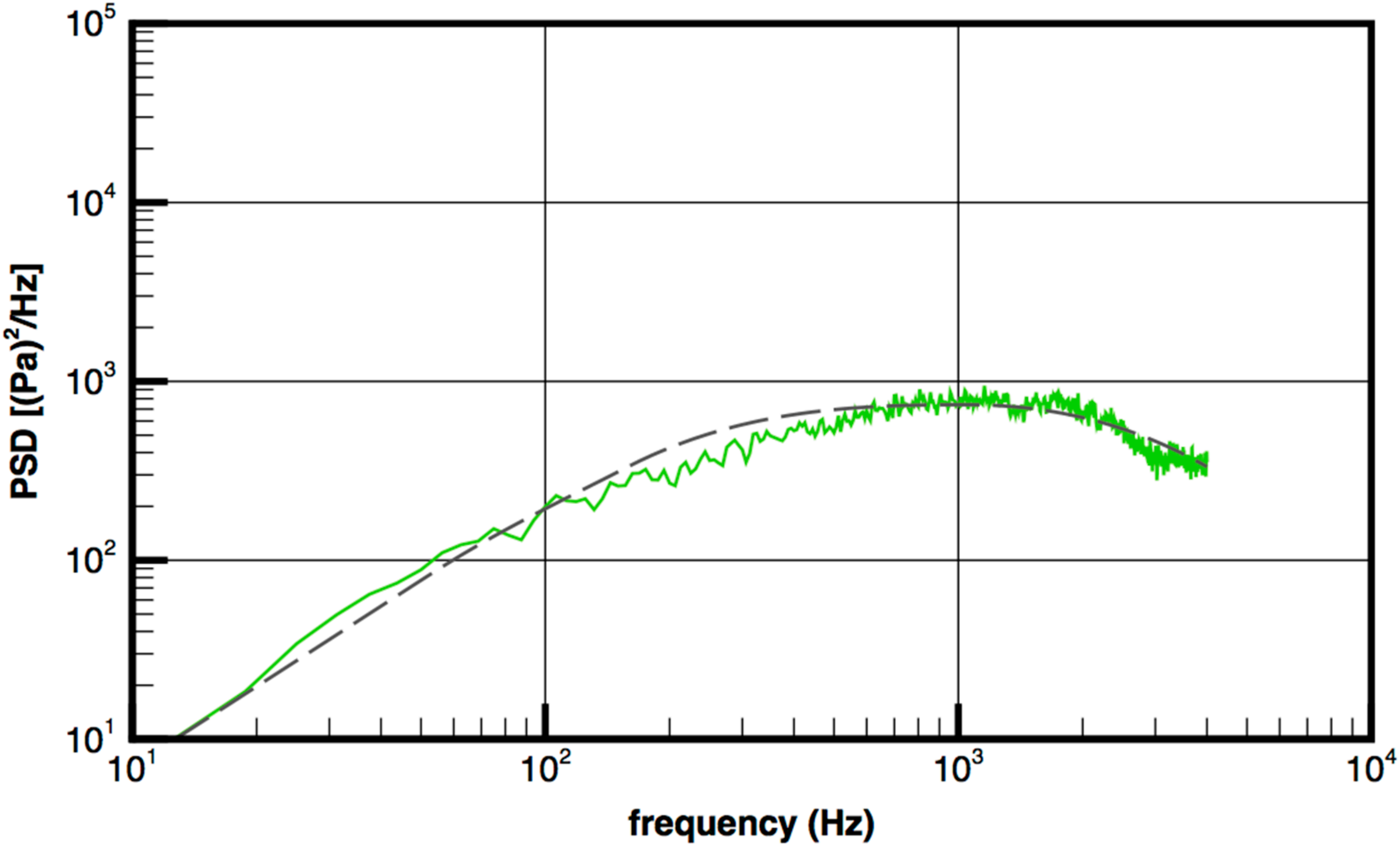
x/D = 12.1, r/D = 4.38, low burn



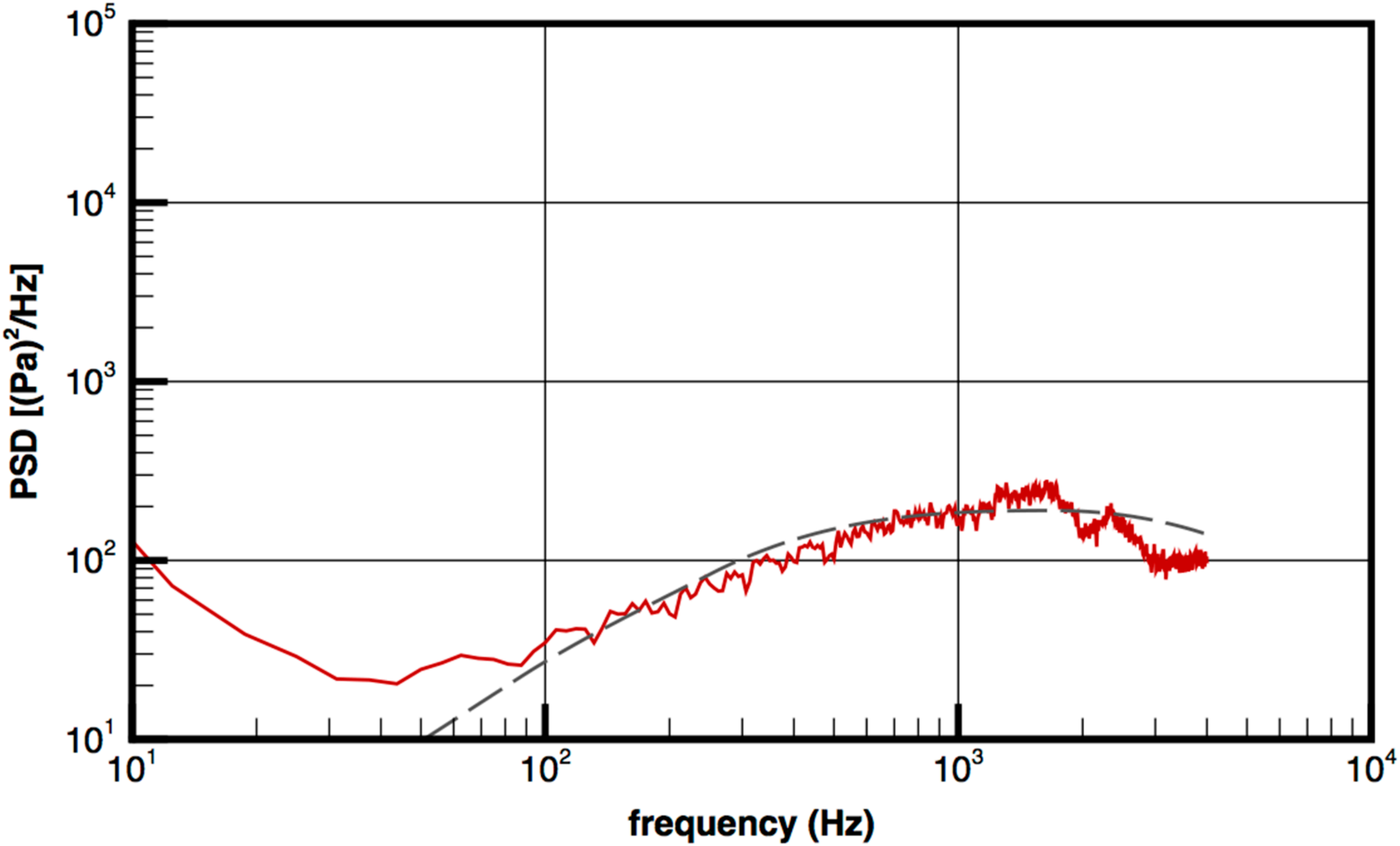
x/D = 12.1, r/D = 6.51, low burn



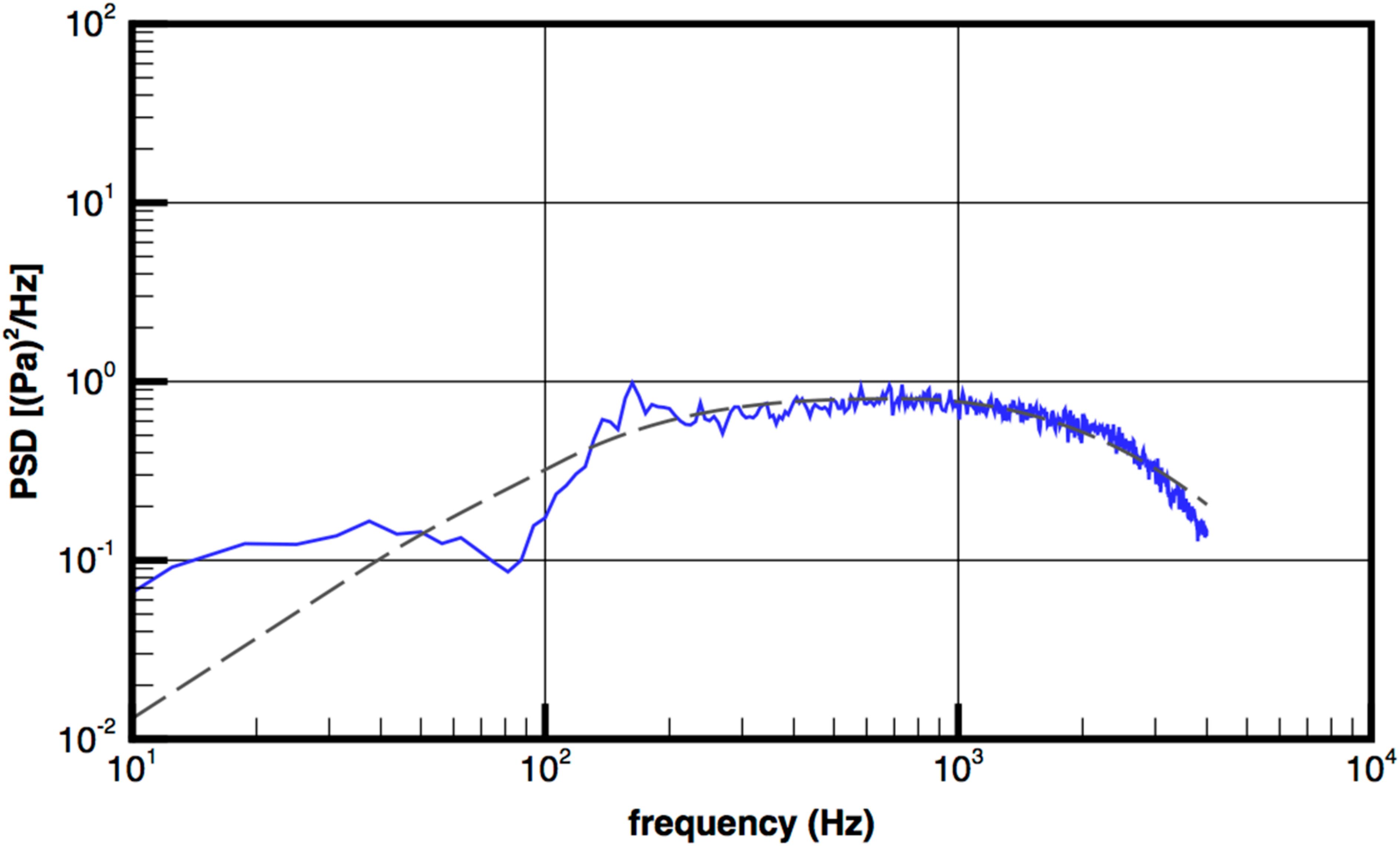
x/D = 12.1, r/D = 8.62, low burn



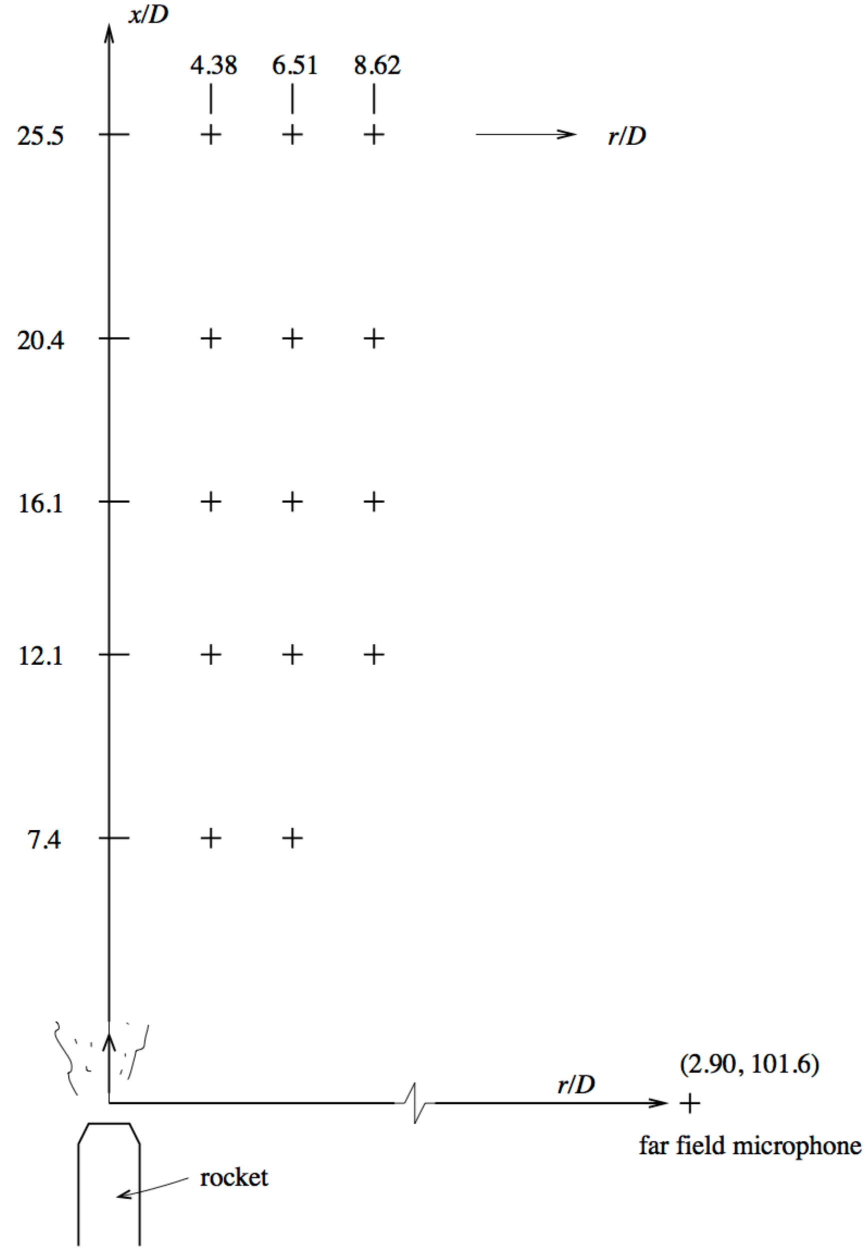
x/D = 7.40, r/D = 4.38, low burn



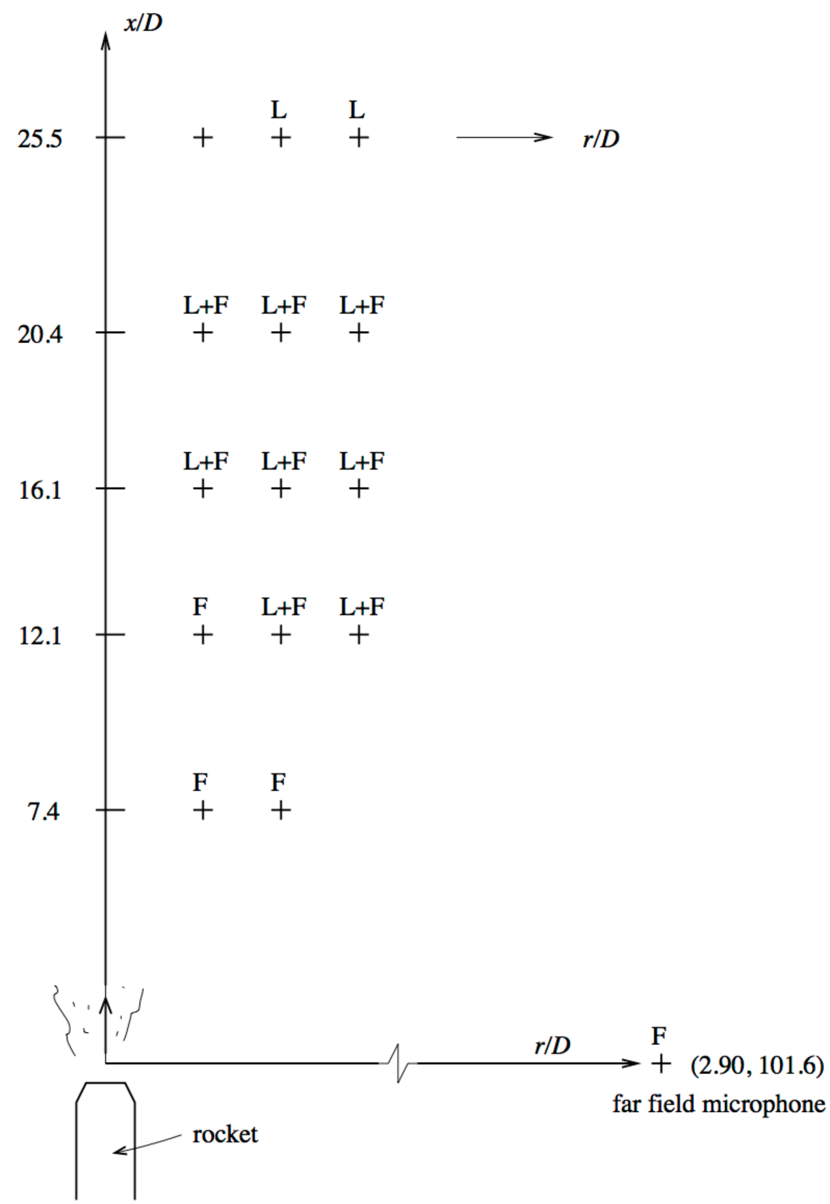
x/D = 7.40, r/D = 6.61, low burn



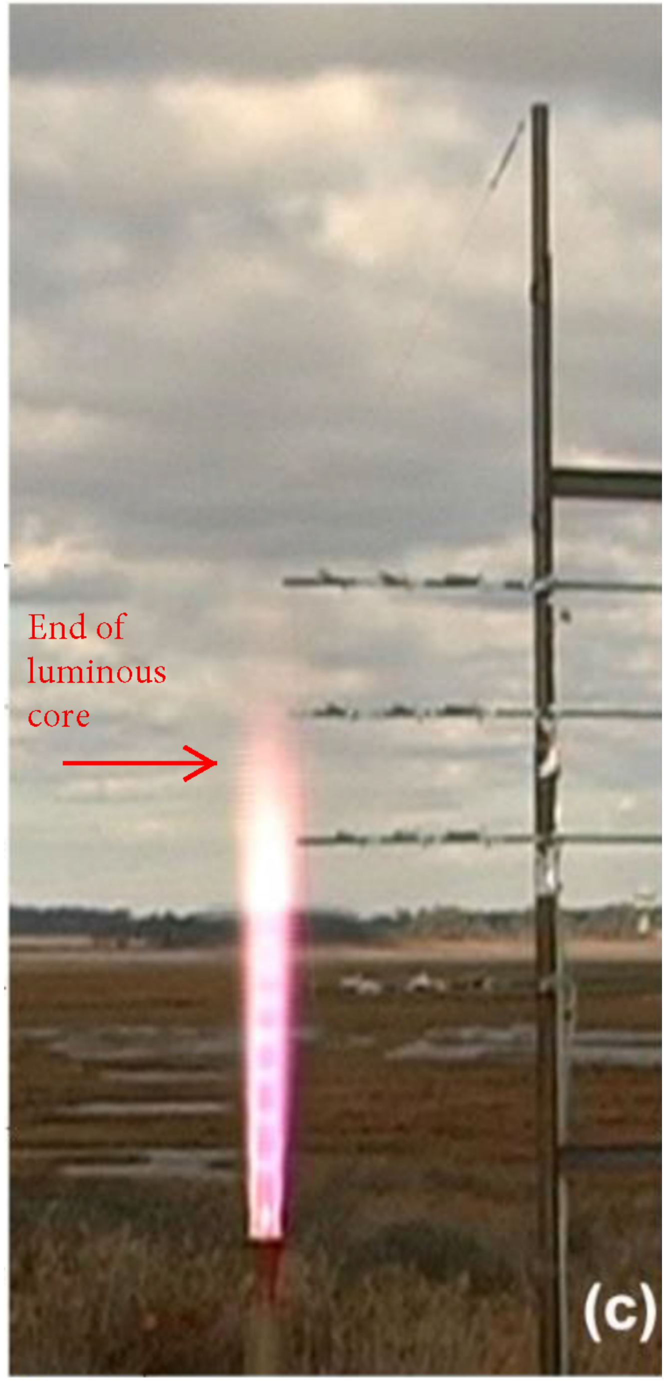
x/D = 2.90, r/D = 101.6, far field, low burn

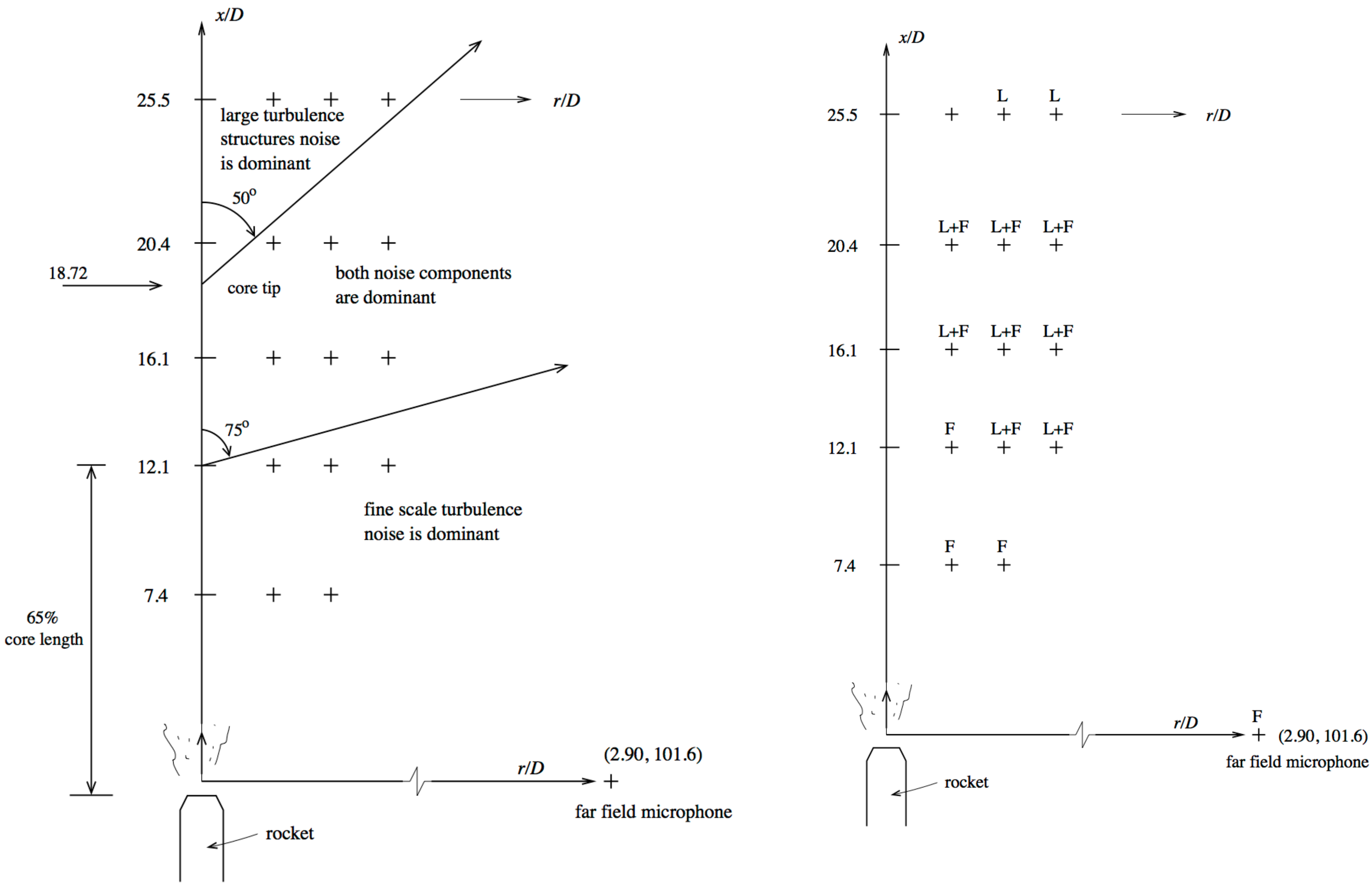


Configuration of near field microphone array. + microphone.



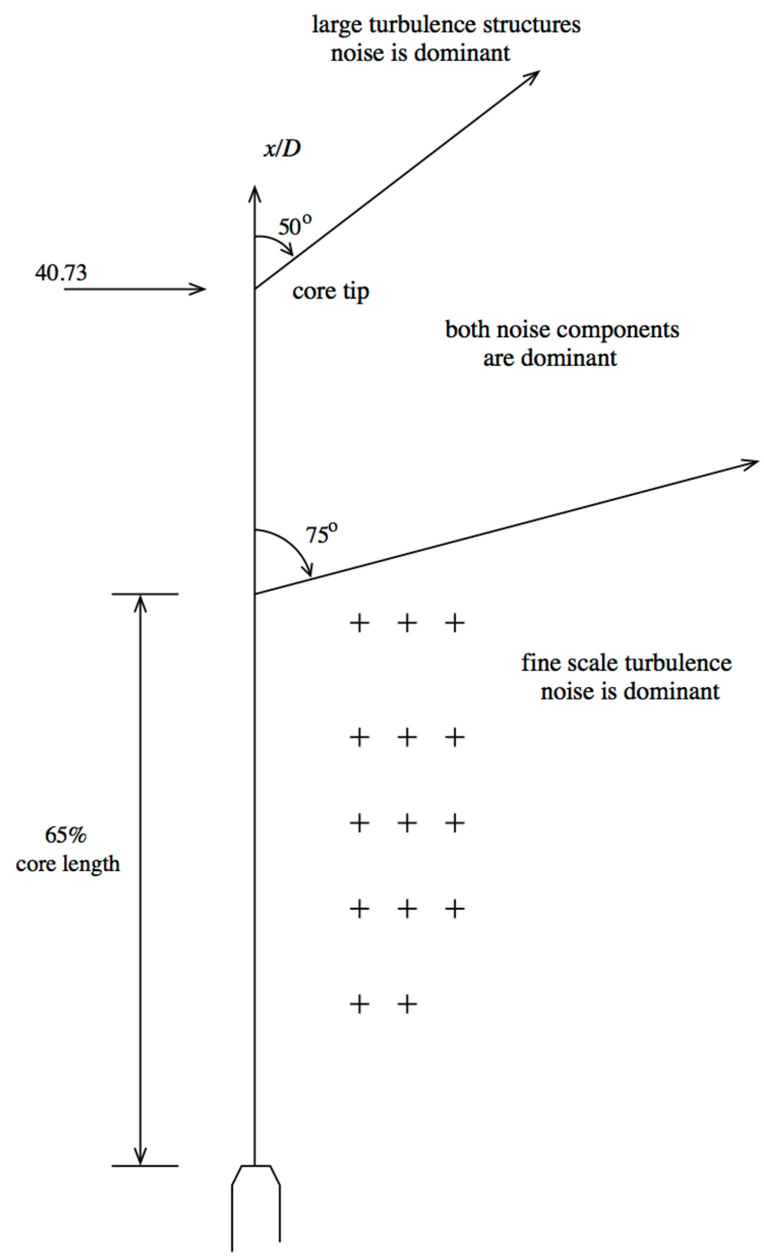
Distribution of dominant noise components measured by the microphone array.
L = Large turbulence structures noise, F = fine scale turbulence noise


End of
luminous
core
(c)

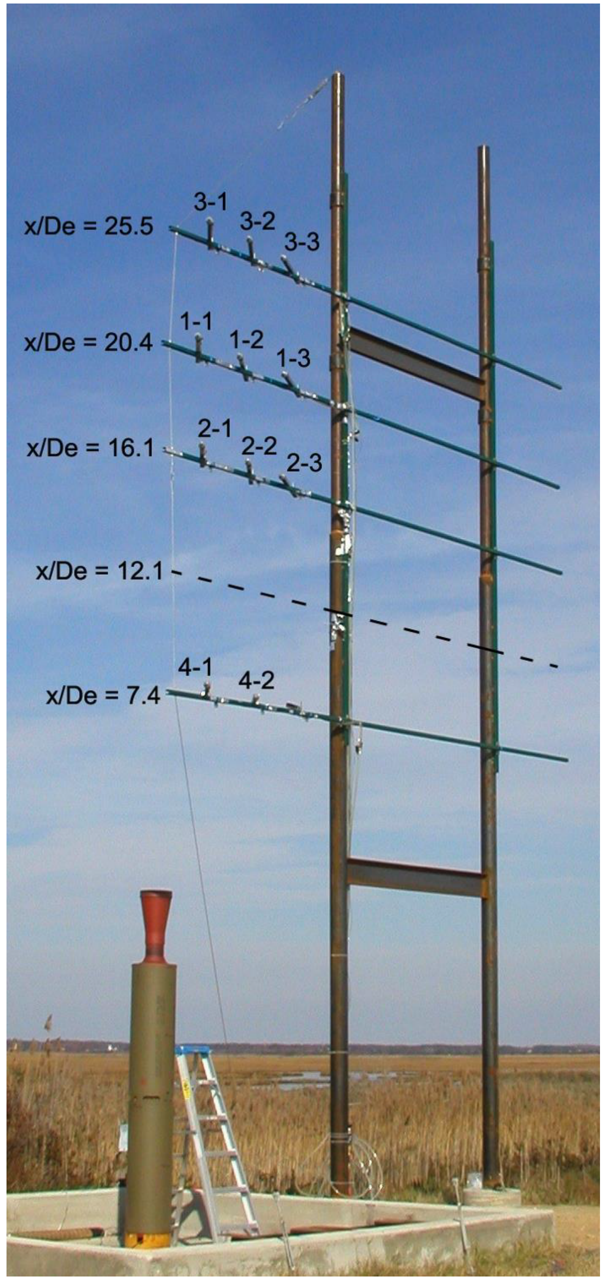


Schematic diagram showing the regions of dominance of the two noise components in the rocket near field at low burn


End of luminous core
(b)



Schematic diagram showing the regions of dominance of the two noise components in the rocket near field at high burn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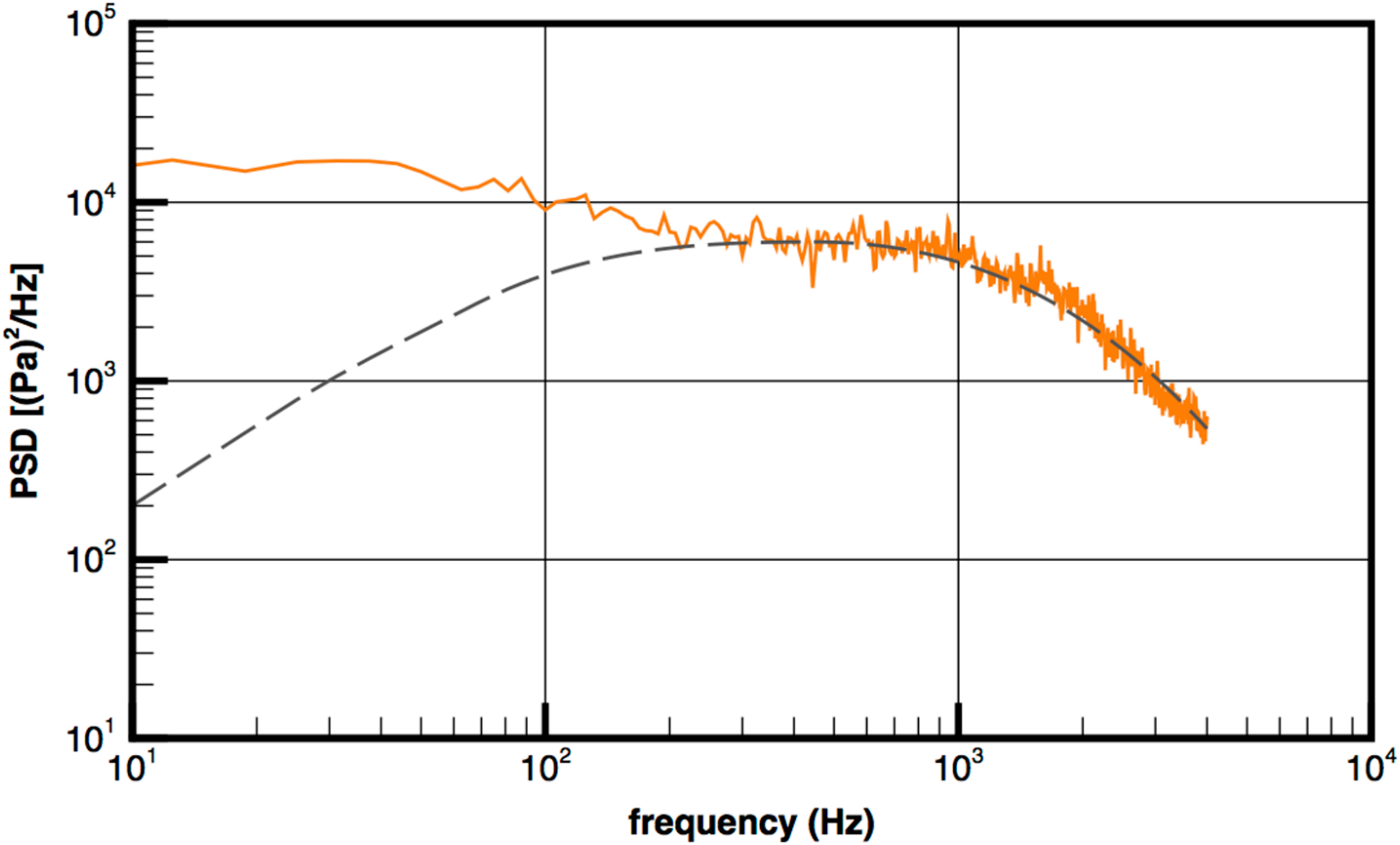
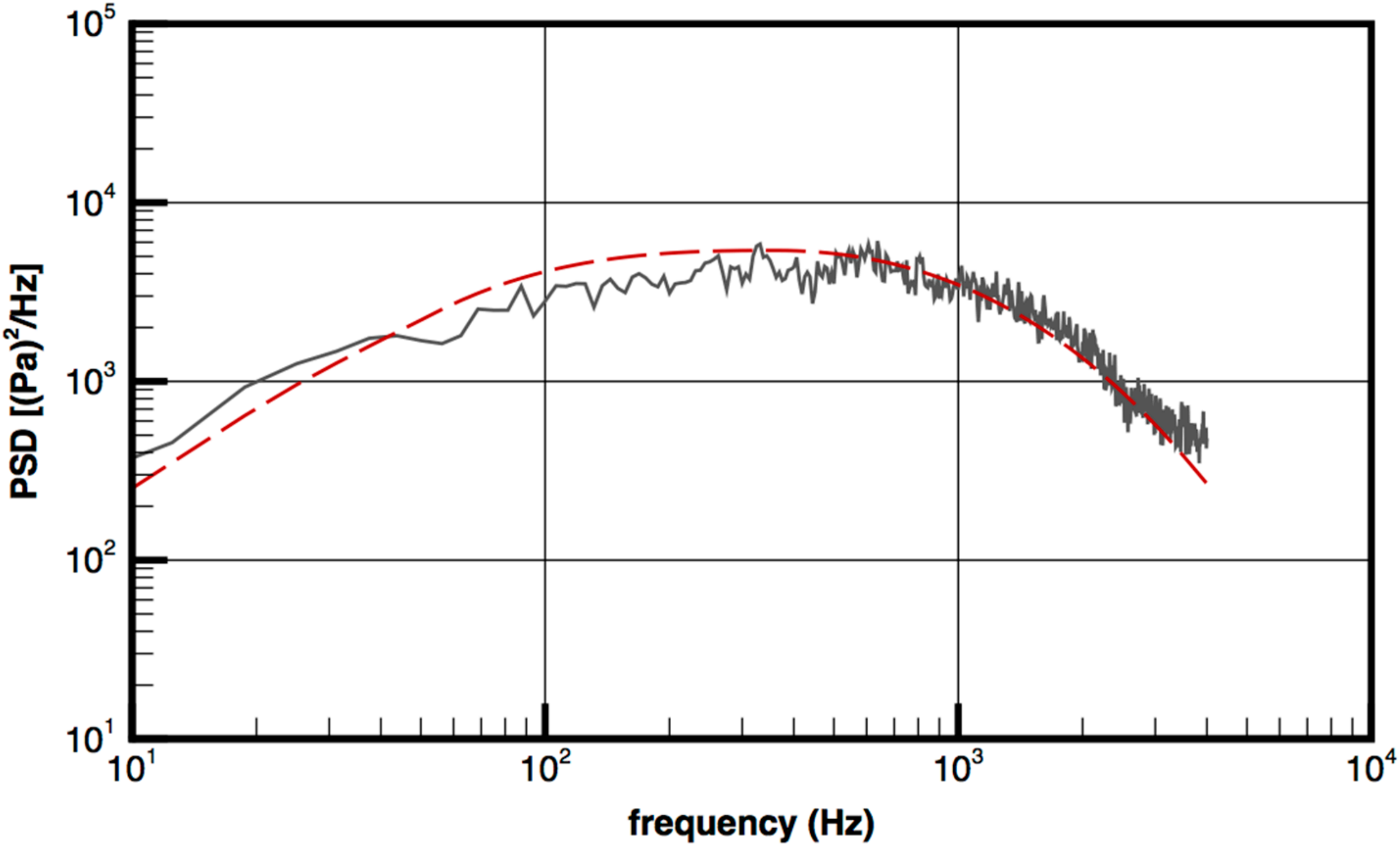
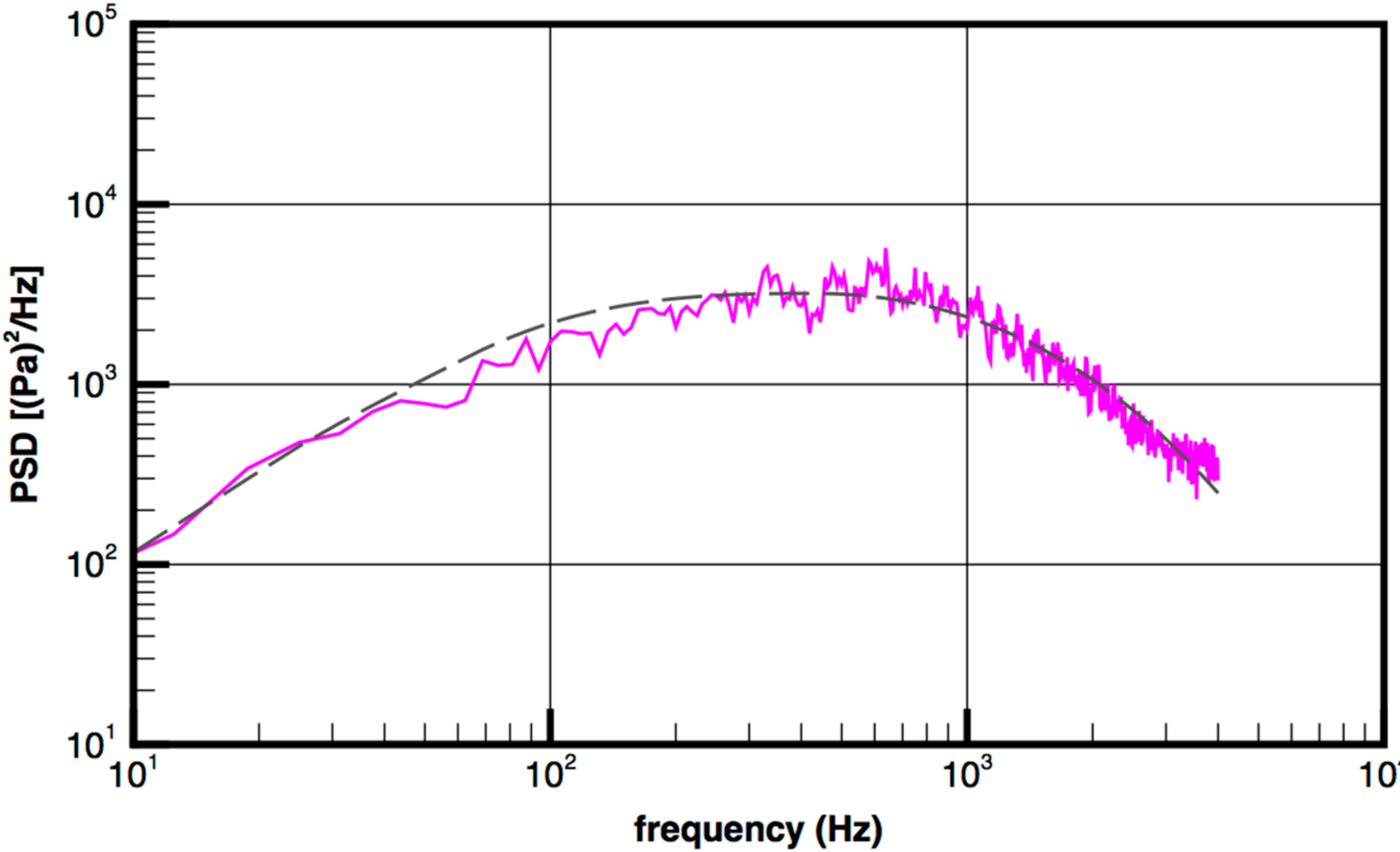


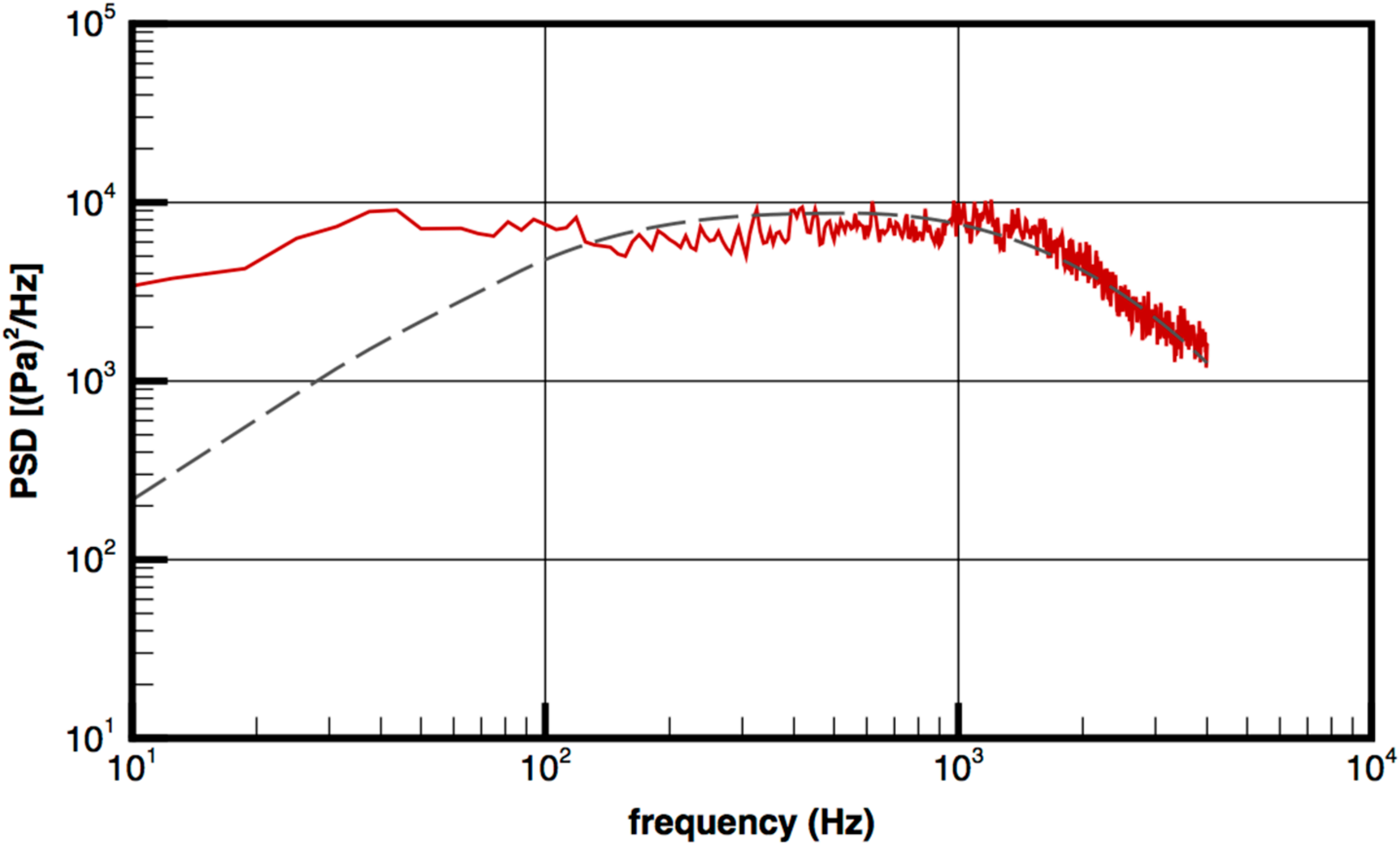
x/D = 25.5, r/D = 4.38, high burn



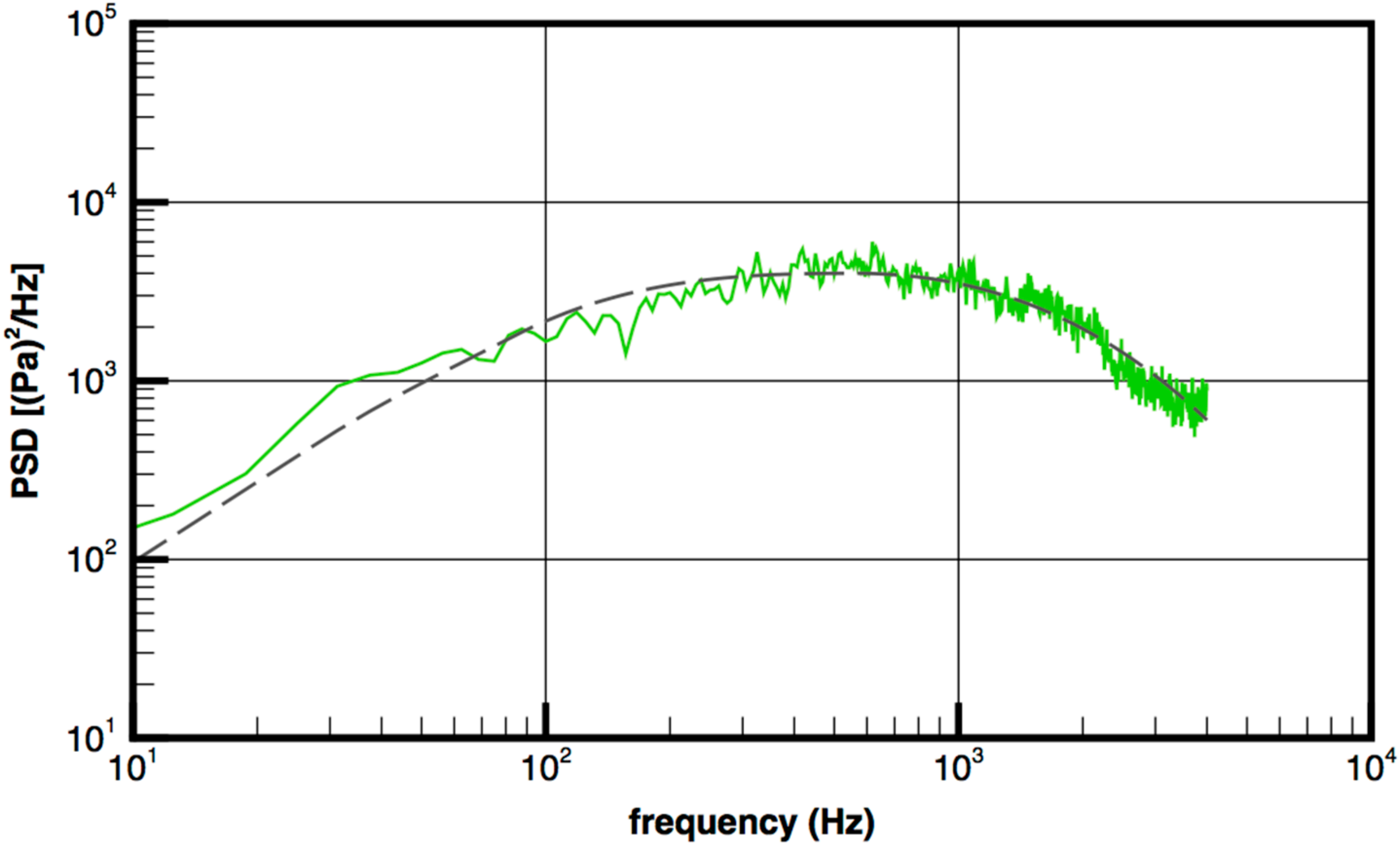
x/D = 25.5, r/D = 6.51, high burn



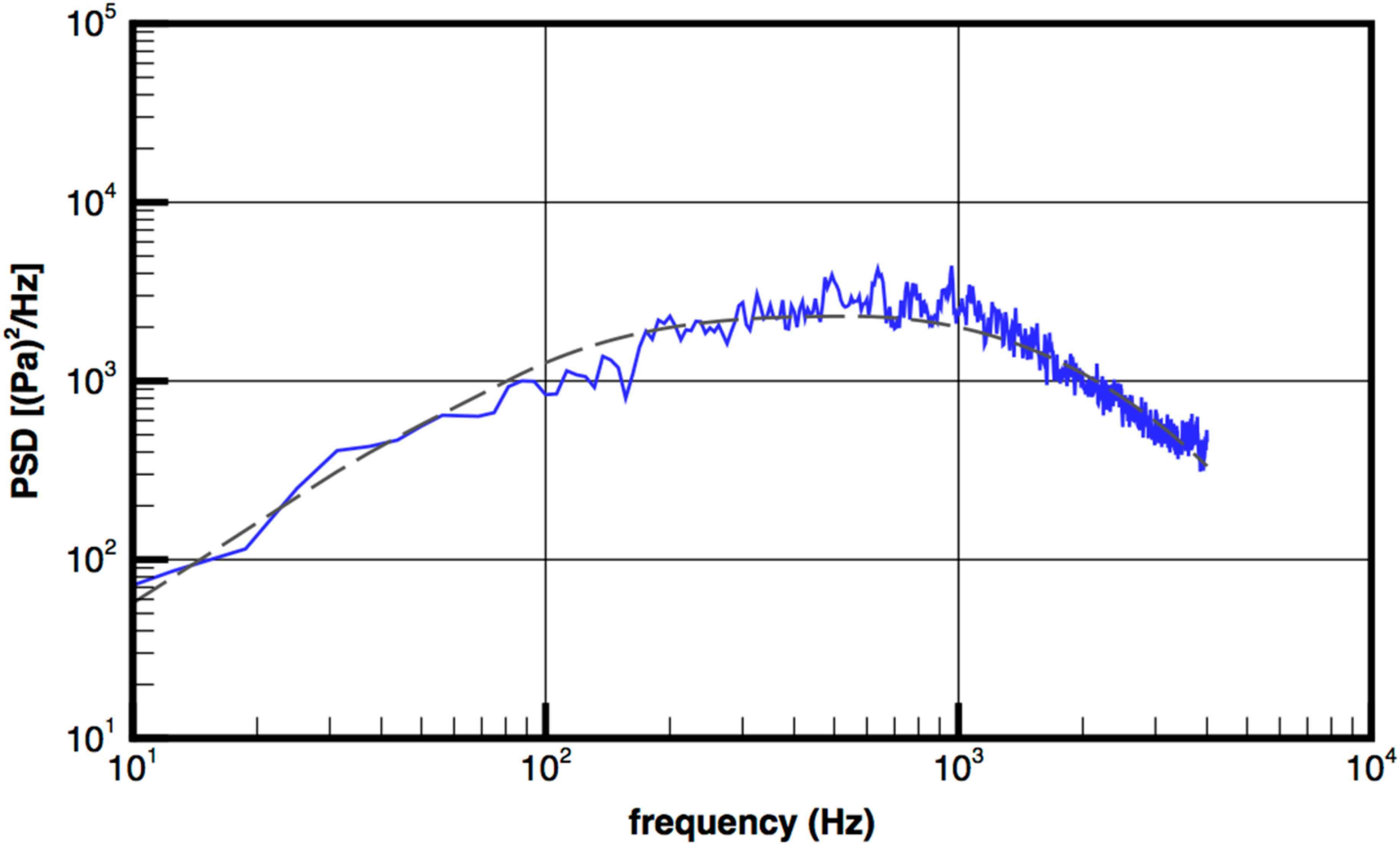
x/D = 25.5, r/D = 8.62, high burn



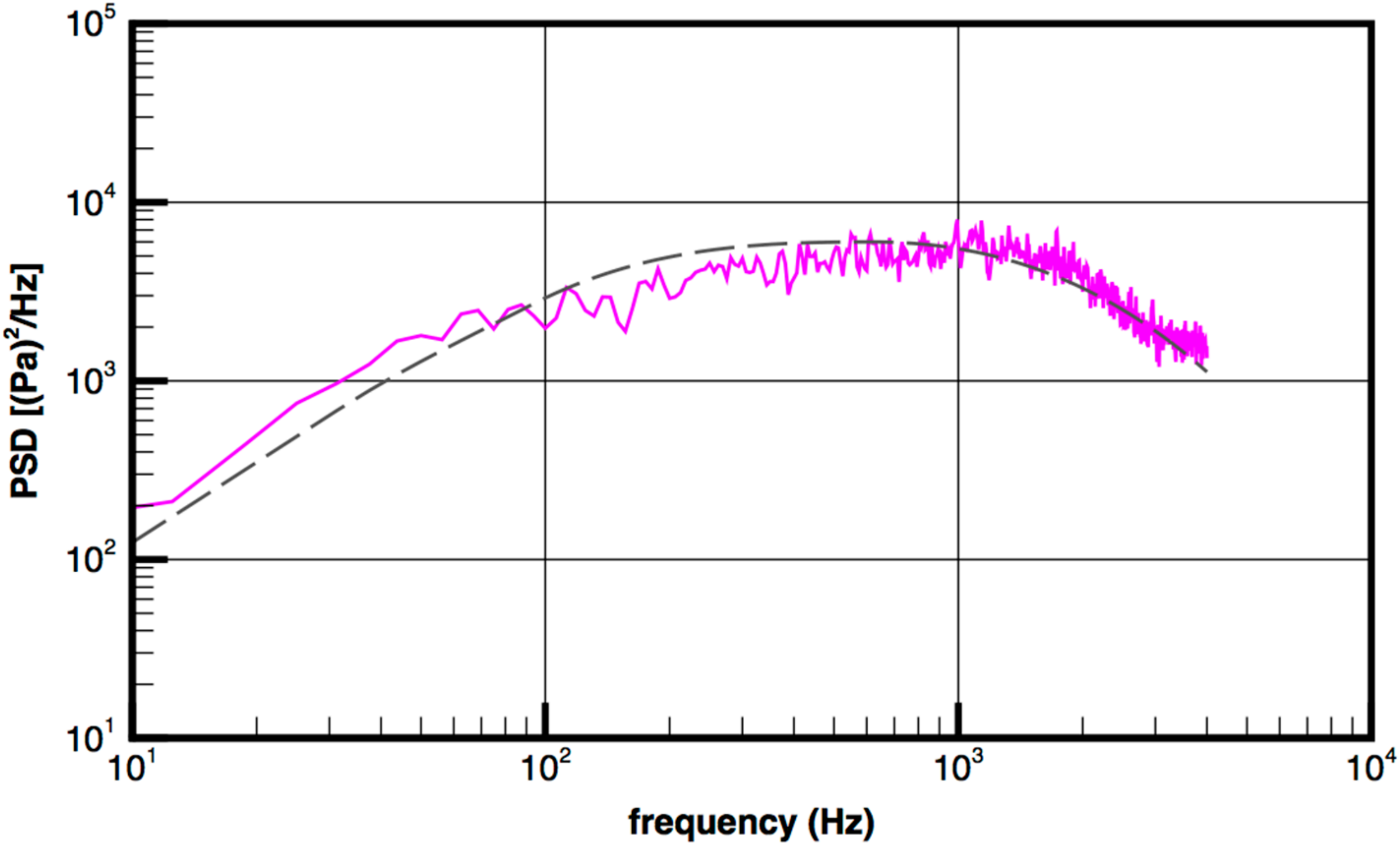
x/D = 20.4, r/D = 4.32, high burn



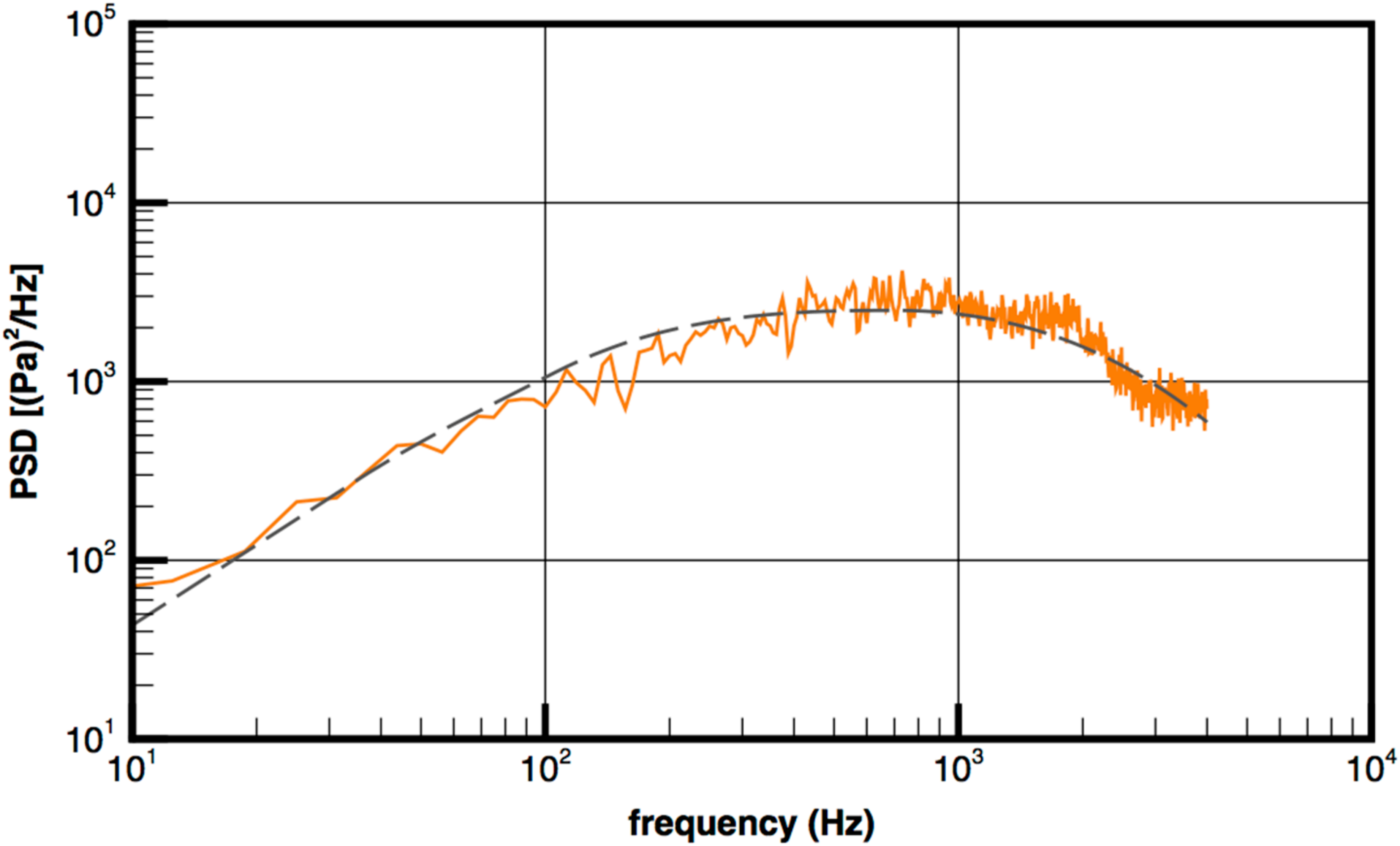
x/D = 20.4, r/D = 6.51, high burn



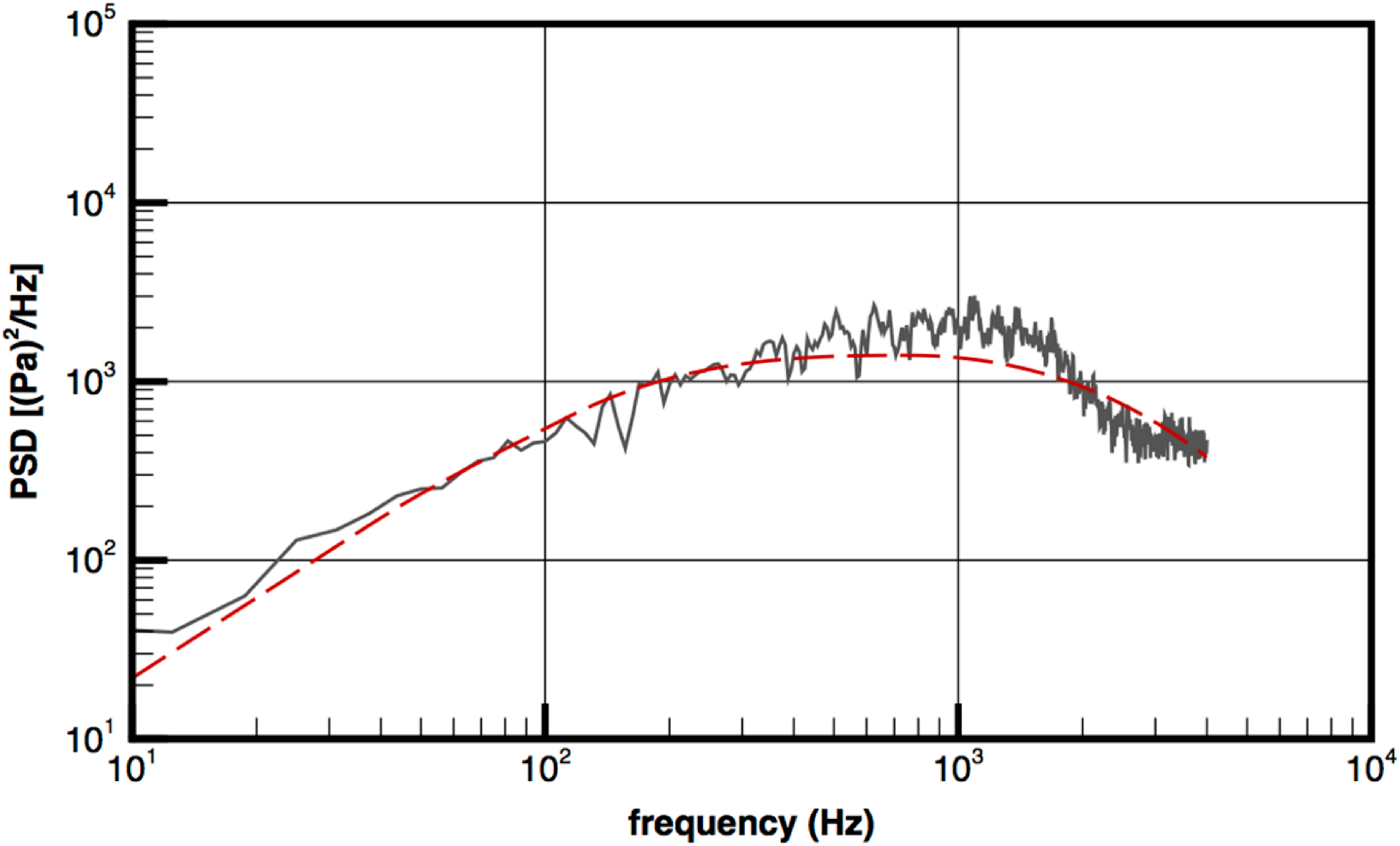
x/D = 20.4, r/D = 8.86, high burn



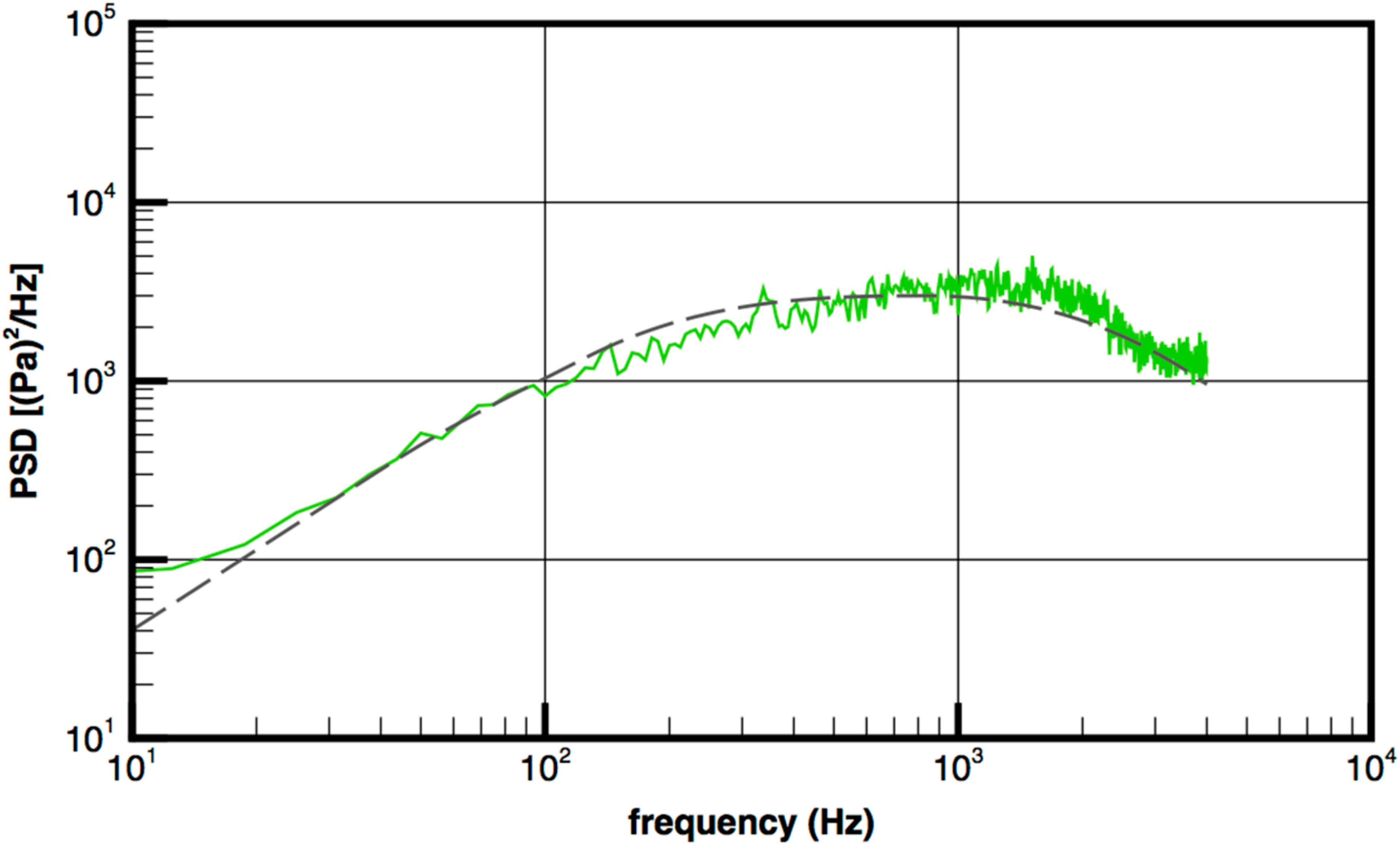
x/D = 16.2, r/D = 4.43, high burn



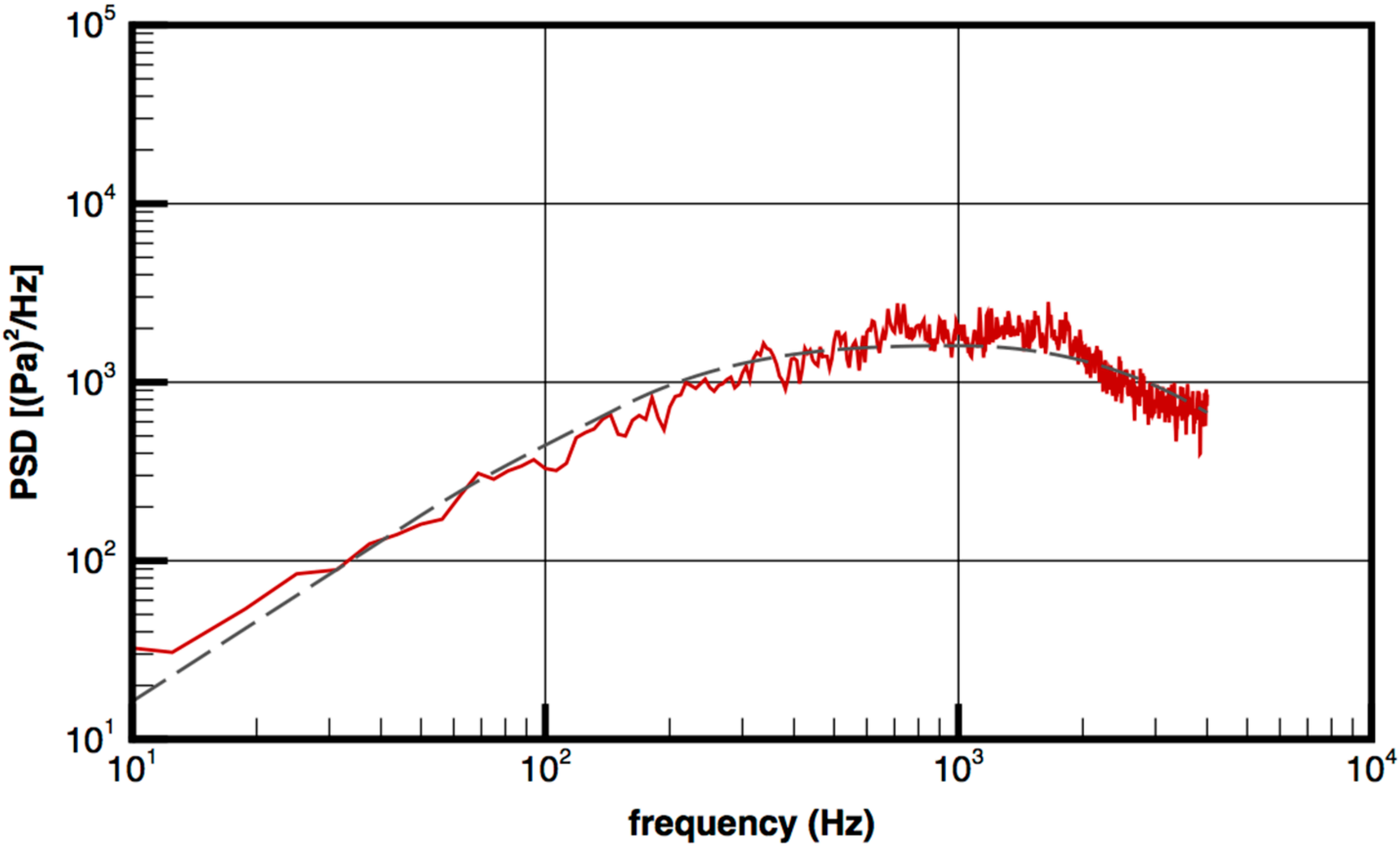
x/D = 16.2, r/D = 6.79, high burn



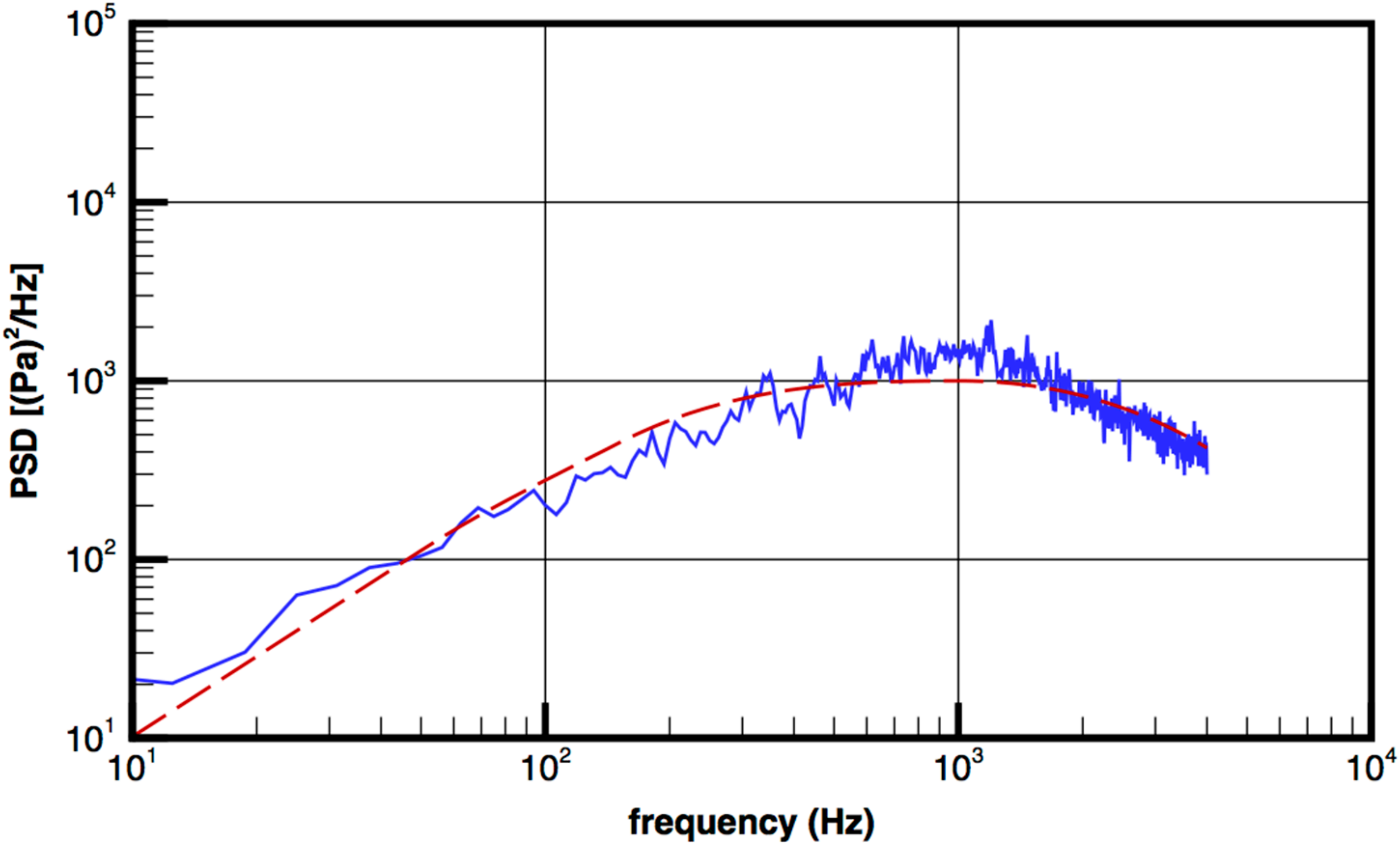
x/D = 16.2, r/D = 8.86, high burn



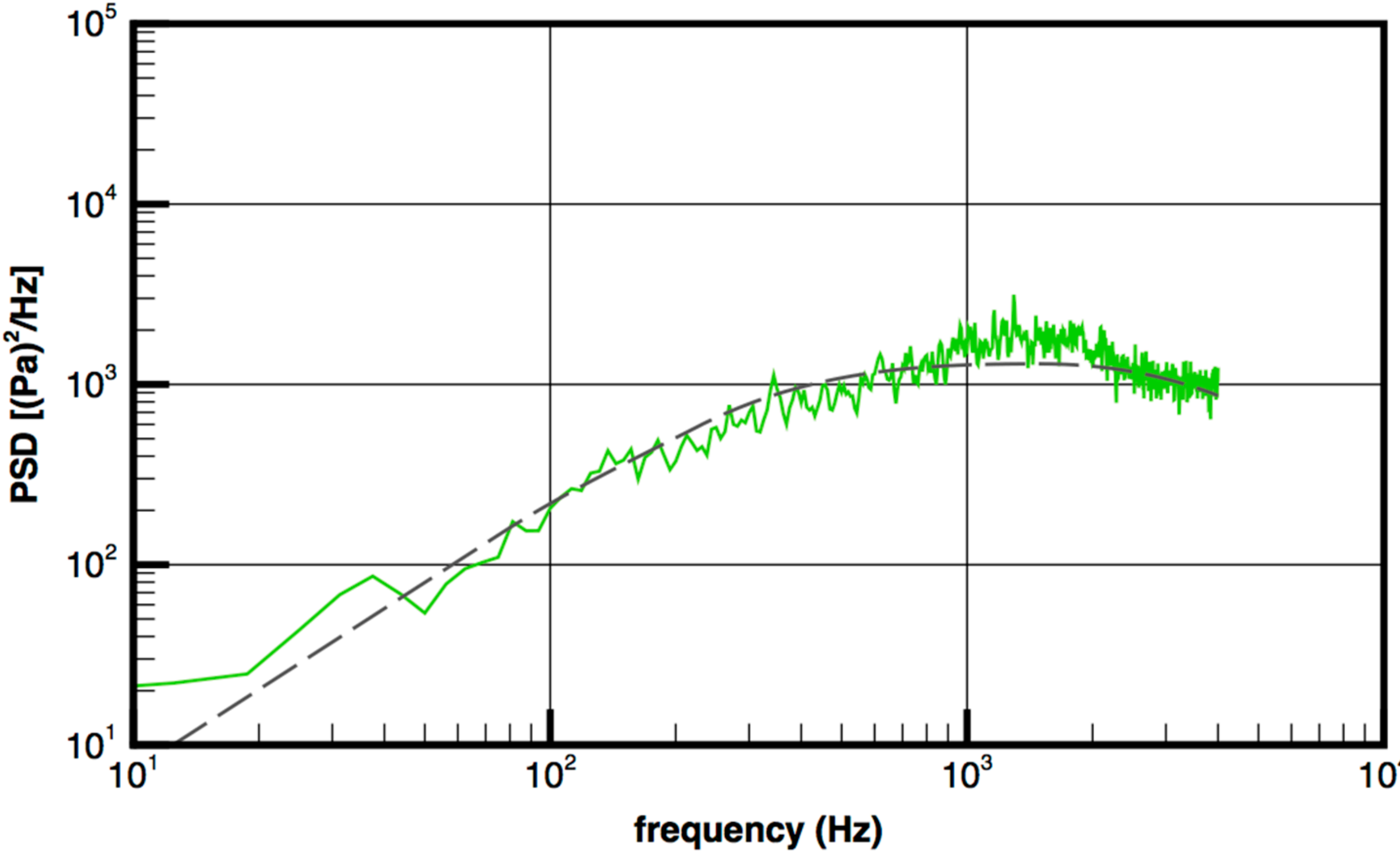
x/D = 12.1, r/D = 4.38, high burn



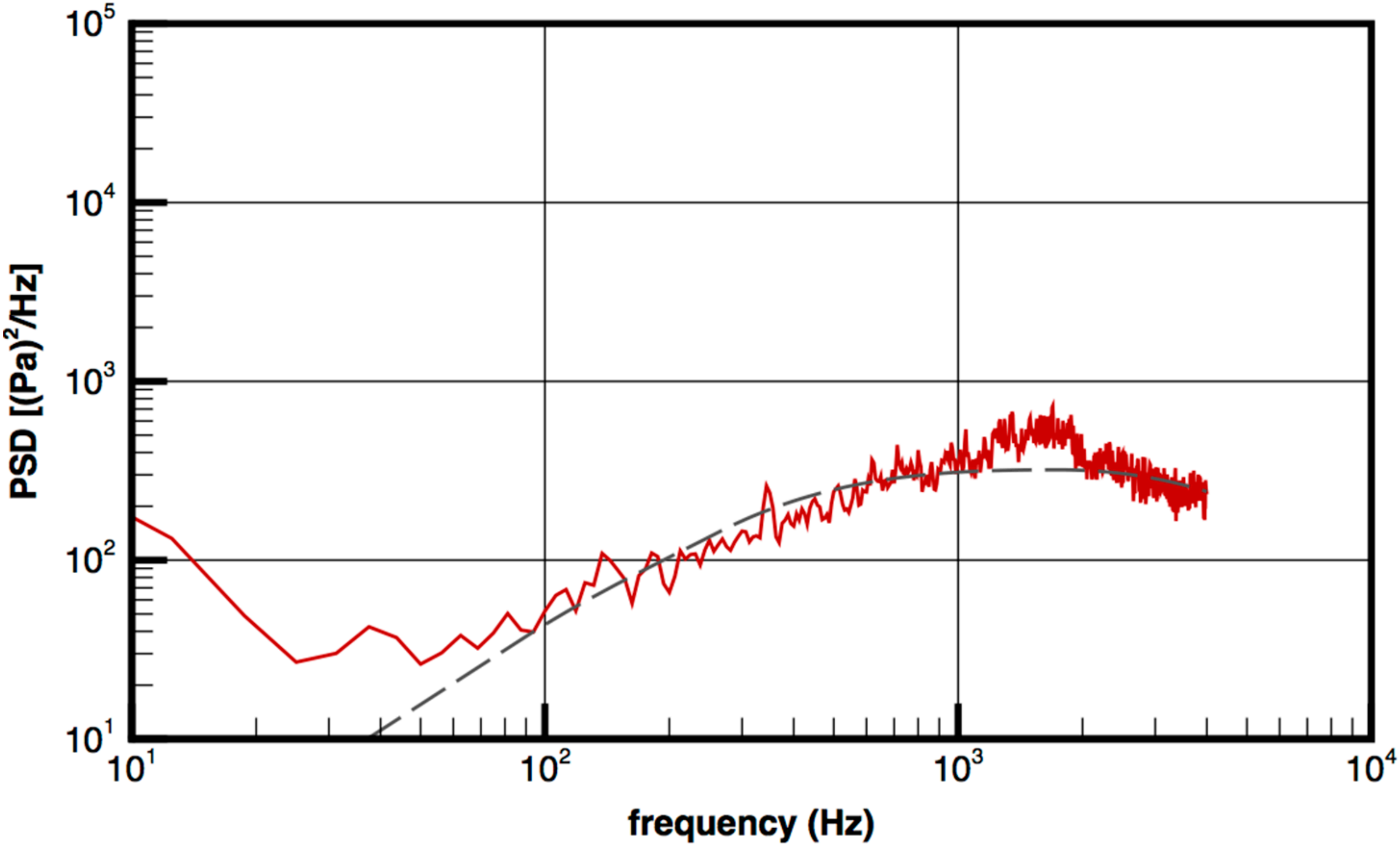
x/D = 12.1, r/D = 6.51, high burn



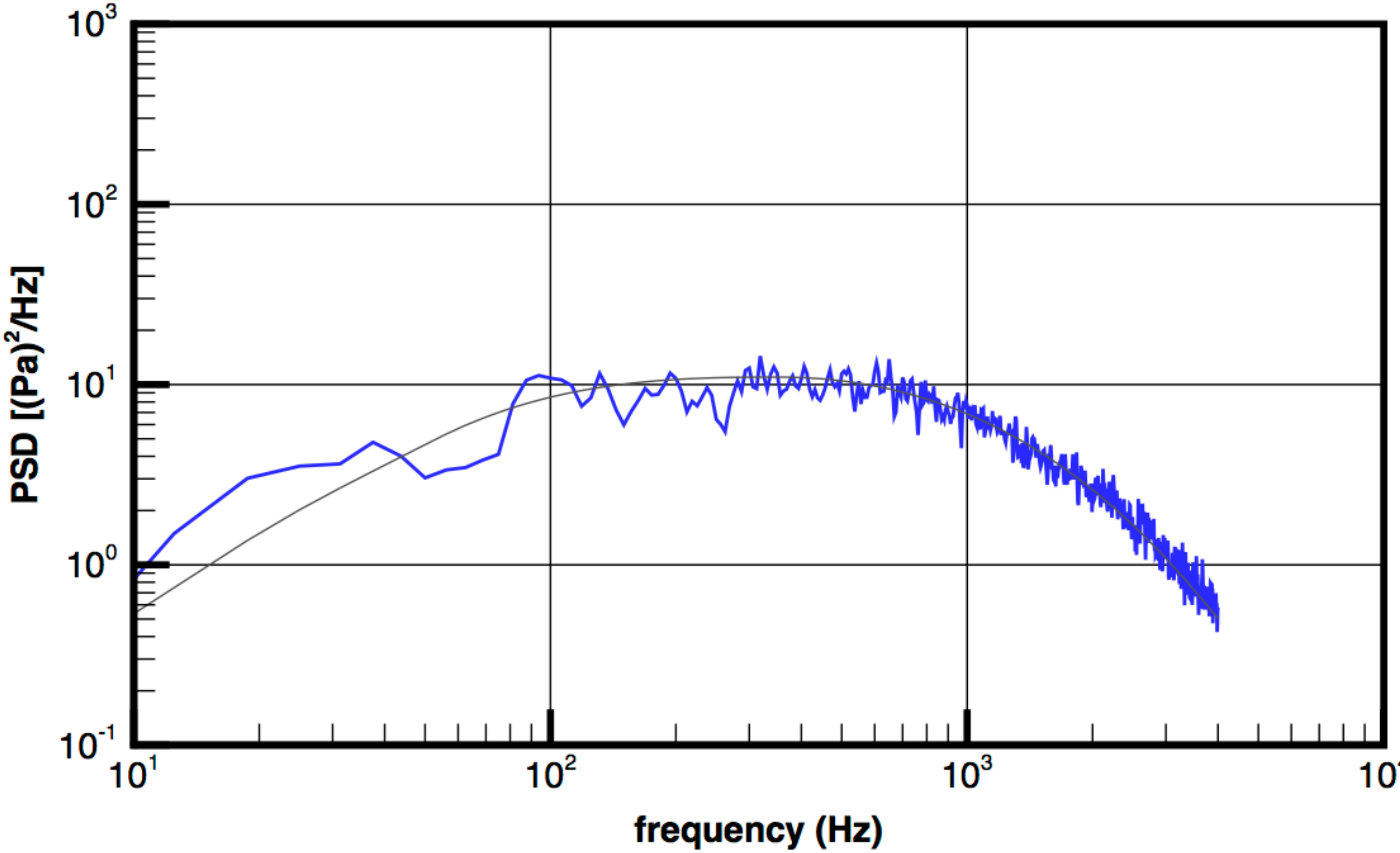
x/D = 12.1, r/D = 8.62, high burn



x/D = 7.4, r/D = 4.38, high burn



$x/D = 7.4$, $r/D = 6.61$, high burn



x/D = 2.9, r/D = 101.6, far field, high burn

Summary and conclusions

1. The two far field similarity spectra of laboratory jets are found to be applicable to the near field noise of solid propellant rockets and hot supersonic jets.

2. In the near field of a solid propellant rocket the noise is dominated by those from the fine scale turbulence and the large turbulence structures of the plume flow, the same as in the case of far field jet noise.

3. Based on the measured data, a semi-empirical near field dominant noise component distribution model for solid propellant rockets is proposed. In this model, the dominant noise components divide the near field into three regions. Fine scale turbulence noise is the sole dominant noise component in the region downstream of the nozzle exit. This is followed by a region where both large turbulence structures noise and fine scale turbulence noise are both dominant. Further downstream the large turbulence structures noise is the only dominant noise component.